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London, Publish'd Oct: 10th 1788, by Geo. Adams, N^o 60 Fleet Street.

ASTRONOMICAL AND GEOGRAPHICAL ESSAYS:

CONTAINING,

I.

A COMPREHENSIVE VIEW OF THE
General Principles of Astronomy.

II.

THE USE OF THE
CELESTIAL AND TERRESTRIAL GLOBES,

Exemplified in a Variety of PROBLEMS, which are designed to illustrate
the Phenomena of the Earth and Heavens, in the most
easy and natural Manner.

III.

THE DESCRIPTION AND USE OF THE
ARMILLARY SPHERE, PLANETARIUM,
TELLURIAN, AND LUNARIUM.

IV.

AN INTRODUCTION TO
PRACTICAL ASTRONOMY;
Or, the Use of the QUADRANT and EQUATORIAL.

By GEORGE ADAMS,

MATHEMATICAL-INSTRUMENT MAKER TO HIS MAJESTY, AND OPTICIAN TO HIS
ROYAL HIGHNESS THE PRINCE OF WALES.

L O N D O N:

Printed for the AUTHOR, by R. HINDMARSH, Printer to His
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and Sold at the Author's Shop, No. 60, Fleet-Street.

M.DCC.LXXXIX.



P R E F A C E.

THE connection of astronomy with geography is so evident, and both in conjunction so necessary to a liberal education, that no man will be thought to have deserved ill of the republic of letters, who has applied his endeavours to diffuse more universally the knowledge of these useful sciences, or to render the attainment of them easier; for as no branch of literature can be fully comprehended without them, so there is none which impresses more pleasing ideas on the mind, or that afford it a more rational entertainment.

The fifth edition of my father's treatise on the globes being out of print, I was solicited to reprint it. To obviate several objections to the
form

form in which he had disposed the problems, I was induced to undertake the present work, in which they are arranged in a more methodical manner, and a great number added to them. Such facts are also occasionally introduced, and such observations interspersed, as it is presumed will excite curiosity, and fix attention.

Having proceeded so far in this work, I found that it was easy to render it subservient to my plan of publishing, from time to time, "ESSAYS, DESCRIBING THE USE OF MATHEMATICAL AND PHILOSOPHICAL INSTRUMENTS:" for the description of those which have been contrived to smoothe the path to the science of astronomy, could no where be introduced with so much propriety, as in a work which treated of it's elementary principles.

To further this design, it was necessary to prefix an introduction to astronomy. This is divided into three parts. In the first, the pupil is supposed to be placed in the sun, the center of the solar system; from this situation he considers the motion of the heavenly host, and finds that all is regular and harmonious. In the second part, his attention is directed to the appearances of the planetary bodies, as observed from the earth.

earth. It were to be wished that the tutor would at this part exhibit to his pupil the various phænomena in the heavens themselves; by teaching him thus to observe for himself, he would not only raise his curiosity, but so fix the impressions which the objects have made on his mind, that by proper cultivation they would prove a fruitful source of useful employment; and he would thereby also gratify that eager desire after novelty, which continually animates young minds, and furnish them with objects on which to exercise their natural activity. In the third part of this introduction, the received, or Copernican system is explained; by this system, the various phænomena of the heavens are rationally accounted for; it shews us how to reconcile the real state of things, with the fallacies arising from the senses; and teaches us that the irregularities observable in the motion of the heavenly bodies, are for the most part to be attributed to the situation from which they are observed. Astronomy, in common with other branches of the mathematics, while it strengthens the powers of the mind, restrains it from rash presumption, and disposes it to a rational assent.

The principles of the Copernican system are further elucidated in the third essay; in which, various planetariums, lunariums, and tellurians,

are described. These instruments, though less complicated in their construction, and less expensive to the purchaser, than those large ones heretofore made for the same purpose, are equally, perhaps better, adapted to explain the general principles of astronomy. In describing them, it was necessary to re-consider many subjects which had been previously treated; but as they are here placed in another point of view, presented to the mind under a different form, are generally described in other words, and often with the addition of new matter, it is hoped that these repetitions, so far from being an object of complaint, will be found to contribute to the main intention of this work, by conveying further instruction, fixing it more deeply in the mind, and rendering that obvious, which before might be found difficult.

One part still seemed wanting to an introductory treatise on astronomy, something that would gently lead the pupil to a knowledge of the practical part of this science, a branch of astronomy to which we are indebted for our present knowledge of the heavens, by which geography has been improved, and by which the passage of ships over the trackless ocean is facilitated.

There

There is no part of mathematical science more simple and easy, than the measurement of the relative positions and distances of inaccessible objects. Yet to the uninstructed, to determine the distance of a ship on the ocean, to ascertain the height of the clouds and meteors that float in the atmosphere, to fix the latitude and longitude of places, &c. are problems that have ever appeared to be above the reach of human art ; they are, therefore, particularly calculated to engage the attention of young minds, and may be used to encourage diligence, and reward application.

To introduce the pupil to this branch of astronomy, I have described three instruments, each of which is simple in it's construction, and two of them of small expence. By these he may find the distance of any inaccessible object, the height of a spire, a mountain, or any other elevation, learn to plot a field, ascertain the altitude of a cloud, a fire-ball, or any other meteor, determine with accuracy the hour of the day, the latitude or longitude of a place, with many other curious problems. In the selection of these, I have to acknowledge the assistance I received from a very ingenious friend.

I had intended to subjoin to this preface a list of astronomical authors, that the reader might know as well where to apply for further information, as the sources from whence I obtained my knowledge of this subject. But the work has swelled so much beyond my expectations, that I am constrained to lay aside this design.

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E S S A Y I.

P A R T I.



ESSAY I.

PART I.

AN ATTEMPT TO EXPLAIN WITH CONCISENESS
AND PERSPICUITY THE GENERAL PRINCIPLES
OF ASTRONOMY.

MANKIND have in all ages been desirous of forming rational conceptions of the nature and motion of those bodies that appear in the vast concave above their heads. Amidst the infinite variety of objects which surround them on every side, the heavenly bodies must have been amongst those which first attracted their attention. They are of all objects the most conspicuous, the most important, and the most beautiful.

Astronomy may be defined as the science which instructs us in the laws, or rules, that govern the heavenly host, and by which their motions are directed. It weighs and considers the powers by which they circulate in their orbs.

It enables us to discover their size, determine their distance, explain their various phænomena, and thus correct the fallacies of the senses by the light of truth.

Astronomy is not merely a speculative science; it's use is as extensive, as it's researches are sublime. Navigation owns it for it's guide: by it commerce has been extended, and geography improved; and thus it has co-operated with other causes in the greatest of all works, the diffusion of knowledge, and the civilization of man.

As in order to attain an accurate idea of any piece of mechanism, it is best to begin our investigations by an examination of those parts which give motion to the rest, and are the primary causes of those effects for which the machine was made; so the young pupil will more easily gain a just idea of the motion of the heavenly bodies, by considering them as seen from the sun, the center of our system, and the principal agent used by the Lord of nature, for conducting and regulating the planetary system.

It will not be difficult after this, to inform him how those appearances are to be accounted for,
that

that arise from his situation, by which he is forced to consider them from a point which is not in the center of the system, and is consequently the source of many apparent irregularities. It will then also be easy to prove to him, that the real and apparent motions of the heavenly bodies are frequently the reverse of each other. For being by this means put into possession of the universals of this science, the knowledge of particulars will be rendered facile and clear.

OF THE SOLAR SYSTEM, AS SEEN BY A SPECTATOR, SUPPOSED TO BE PLACED IN THE SUN.

As the center of the system is the only place from which the motion of the planets can be truly seen, let us suppose our observer placed at the center of the sun. In this situation he will see at one view all the heavens, which will appear to him perfectly spherical, and the stars as so many lucid points in the concave surface of the sphere; the center of which is the sun, or, in the present instance, the eye of the observer.

Our spectator will not, however, immediately conclude from appearances, either that the heavens are really spherical, or that the sun is in the

center of the sphere, or that the stars are all at an equal distance from him; having been taught by experience and observation, that while he remains in the same place, he cannot judge properly of the distance of surrounding objects, at least of those which are placed beyond the ordinary reach of his view: for beyond that distance, all the principles by which we form our general judgment fail us, and we can only tell which is nearest, or which is furthest, either by our own motion, or that of the objects.

To illustrate this, let us suppose a number of lamps, to be placed irregularly, at different distances from the eye, in a dark night. Now as in this case, we suppose the darkness to be so complete, that no intermediate objects could be seen, no difference in colour discerned, nor any perception of a convergence towards the point of sight, our judgment could not assist us in distinguishing the distance of one from the other, and they would therefore all seem to be at an equal distance from the spectator.

For the same reason, the sun and moon, the stars and planets, appear to be all at an equal distance from us; though it is highly probable, that some of the stars are many millions of times
nearer

nearer to us than others. The sun is demonstrated to be nearer than any of the stars. The moon and some of the planets are known by ocular proof to be nearer to us than the sun, because they sometimes come between it and our eye, and hide the whole, or a great part of his disk, from our view. They all, however, appear equally distant, and to be placed in the surface of a sphere, whereof our eye is the center. In whatever place, therefore, the spectator resides, whether it be on this earth, in the sun, or in the regions of Saturn, he will consider that place as the middle point of the universe, and as the center of the world; for it will be to him the center of that spherical surface, in which all distant bodies appear to be placed.

Here the tutor will find his advantage in illustrating this subject, and extending the ideas of his pupil, by actual experiments on real objects. Young people should be taught to gain as much information as possible from sensible images; by these their mind would be gradually led to feel it's powers, and soon learn to correct those errors which are induced into it by appearances, derived only from the senses. No man can at once convey light in the higher subjects to another man's understanding. It must come

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into

into the mind from it's own motions, within itself; and the grand art of philosophy and education, is to set the mind in action, and even when we think nothing of it, to assist it in it's labour.*

The pupil may now proceed to consider the observations of the solar spectator; to whom, as we have already observed, the heavens will appear as the surface of a concave sphere, concentrical to his eye: in this surface he will discover an innumerable host of fixed stars, which will for some time engage his attention, before he discovers that they may be distinguished into two kinds; the one dispersed through the whole heavens, differing in their degree of brightness, but remaining always at the same relative distance from each other. These he will therefore call FIXED STARS, or only STARS. Besides these, he will find some others moving among the foregoing with different velocities, which he will call WANDERING STARS, or PLANETS.

Here, however, it may be proper to observe, that what we call the sky, in which the heavenly bodies seem as it were to be fixed, is no real substance.

substance. If there was no atmosphere surrounding our earth, whose particles might reflect other rays of light to our eyes, than those which come directly from the sun, all parts of the heavens, even at mid-day, would be dark, and the stars be visible at noon. But as our atmosphere abounds with particles capable of reflecting light every way, some of it will fall upon our eyes whithersoever they are directed; from the nature of this reflection, we receive the idea of colour, and the mind immediately imagines a substance wherein it may reside; in the same manner, the regular reflection of light from an object in a looking glass, is combined by the mind into an image of that object.

Mr. de Saussure, when on the top of Mount Blanc, in Savoy, a mountain which is elevated 15673 feet perpendicularly above the sea, and where consequently the atmosphere must be much rarer than our's, says, that the moon shone with the brightest splendor in the midst of a sky as black as ebony; while Jupiter, rayed like the sun, rose from behind the mountains in the east.*

OF

* Appendix to vol. 74, Monthly Review.

OF THE CELESTIAL SIGNS AND CONSTELLATIONS.

Having proceeded thus far, our spectator will endeavour to find out some method of distinguishing the stars from each other; concluding, that as they do not change their relative positions one to the other, he may make an exact description of them, and by repeated observations determine the position and order which subsists among them.

That he may avoid confusion in description, and be able to point out any particular star, without being obliged to give a name to each, he will divide them into several parcels; to each of these parcels he will assign a figure at pleasure; these assemblages, or groupes of stars, he will call CONSTELLATIONS.

Thus a number of stars near the north pole is called the bear, because the stars which compose it are at such distances from each other, that they may fall within the figure of a bear. Another constellation is called the ship, because that collection of stars which compose it, is represented upon a celestial globe as comprized within some part of the figure of a ship.

As the fixed stars will appear to our observer of different degrees of magnitude and splendor, he will divide them into six different classes. Those which seem the largest and brightest, he will call stars of the first magnitude; the smallest that we can see with the naked eye, are called stars of the sixth magnitude; and the intermediate ones, according to their different apparent sizes, he will call of the second, third, fourth, or fifth magnitudes. Those stars which cannot be seen without the assistance of a telescope, are not reckoned in any of these classes, and are called **TELESCOPIC STARS.**

By a knowledge of the fixed stars and their positions, our observer will obtain so many fixed points, by which he may observe the motions of the planets, and the relation of these motions to each other. For from the same place, these motions can only be estimated by the angle formed at the spectator's eye by the space which the moving body passes over.

To measure these spaces, the stars must be used, and considered as so many luminous points fixed in the concavity of a sphere, whose radius is indefinite, and of which the observer's eye is the center. We may learn from hence the necessity
of

of forming an exact catalogue of the stars, and of determining their positions with accuracy and care. With such a catalogue, the science of astronomy begins.

Although to those who are unacquainted with the nature of celestial observation, it might at first sight appear almost impossible to number the stars; yet their relative situations have been so carefully observed by astronomers, that they have not only been numbered, but even their places in the heavens have been ascertained with greater accuracy, than the relative situation of most places on the surface of the earth.

The greatest number of stars that are visible to the naked eye, may be seen in a winter's night, when the air is clear, and no moon appears. But even then, a good eye can scarce distinguish more than one thousand at a time in the visible hemisphere: for though on such a night they appear to be almost innumerable, this appearance is a deception, that arises from our viewing them in a transient and confused manner; whereas, if we view them distinctly, and only consider a small portion of the heavens at a time, and after some attention to the situation of the remarkable stars contained in that portion, begin to count, we shall

shall be surprized at the smallness of their number, and the ease with which they may be counted.

Hipparchus, the Rhodian, about an hundred and twenty years before the birth of Christ, was the first among the Greeks who reduced the stars into a catalogue; daring, according to Pliny, “to undertake a thing, which seemed to surpass the power of a divinity; that is, to number the stars for posterity, and to reduce them into order; having contrived instruments, by which he marked the place and magnitude of each star. So that by these means we can easily discover, not only whether any of the stars perish, and others grow up, but also whether they move, and if so, the direction of their motion, whether they increase or diminish; thus putting posterity in possession, as it were, of the heavens.”

Several astronomers have followed Hipparchus in the same arduous undertaking. In 1603, J. Bayer published celestial charts of all the known constellations, and of the visible stars of which they are composed. In these charts every star is distinguished by a letter. The largest star in the constellation is marked with the first letter of the Greek alphabet; the next in apparent size

is marked with the second letter, and so on. If there are more stars in the constellation than there are letters in the Greek alphabet, he marks the remainder with the letters of the Roman alphabet.

When a star is mentioned with the letters of the Greek or Roman alphabet, it is always with the additional name of the constellation to which it belongs ; and thus to those who are acquainted with the figures of the constellations, and with the catalogue of fixed stars, it becomes as determinate a denomination, as if the star was called by a proper name, and the same purpose is answered in a more familiar manner, and with less burthen upon the memory.

The number of the ancient constellations was 48 ; in these were included 1022 stars. Many constellations have been added by modern astronomers ; so that the catalogues of Flamsteed and De la Caille, when added together, are found to contain near five thousand stars. The names of the constellations, their situation in the heavens, with other particulars, are best learned by studying the artificial representation of the heavens, a celestial globe.

The stars appear of a sensible magnitude to the naked eye, because the retina is not only affected by the rays of light which are emitted directly from them, but by many thousand more, which, falling upon our eye-lids, and upon the visible aerial particles about us, are reflected into our eyes so strongly, as to excite vibrations, not only in those points of the retina, where the real images of the stars are formed, but also in other parts round about it. This makes us imagine the stars to be much bigger, than they would be if we saw them only by the few rays which come directly from them to our eyes, without being intermixed with others. Any one may be made sensible of this, by looking at a star of the first magnitude, through a long narrow tube ; which, though it takes in as much of the sky as would hold a thousand of such stars, scarce renders that one visible.

The number of the stars almost infinitely exceeds what we have yet been speaking of. An ordinary telescope will discover, in several parts of the heavens, ten times as many stars as are visible to the naked eye. Hooke, in his *Micrographia*, says, that with a telescope of twelve feet he discovered seventy-eight stars among the pleiades, and with a more perfect telescope, many more.

Galileo

Galileo reckoned eighty in the space between the belt and the sword of Orion, and above five hundred more in another part of the same constellation, within the compass of one or two degrees square. Antonia Maria de Rheita counted in the same constellation above two thousand stars. Future improvements in telescopes may enable us to discover numberless stars that are now invisible; and many more there may be, which are too remote to be seen through telescopes, even when they have received their ultimate improvement. Dr. Herschel, to whose ingenuity and assiduity the astronomical world is so much indebted, and of whose discoveries we shall speak more largely in another part of this essay, has evinced what great discoveries may be made by improvements in the instruments of observation. In speaking here of his discoveries, I shall use the words of M. de la Lande.* “In passing rapidly over the heavens with his new telescope, the universe increased under his eye; 44000 stars, seen in the space of a few degrees, seemed to indicate that there were seventy-five millions in the heavens.” But what are all these, when compared to those that fill the whole expanse, the boundless

* *Memoires de l'Academie de Dyon*, 1785.

boundless fields of ether; indeed, the immensity of the universe must contain such numbers, as would exceed the utmost stretch of the human imagination. For who can say, how far the universe extends, or where are the limits of it? where the Creator stayed "his rapid wheels;" or where he "fixed the golden compasses?"

OF THE PLANETS, AS SEEN FROM THE SUN.

Our solar observer having attained a competent knowledge of the fixed stars, will now apply himself to consider the planets: these, as we have already observed, he will soon distinguish, by their motion, from the fixed stars; the stars always remaining in their places, but the planets would be seen passing by them with unequal velocities. Thus on observing the earth, for instance, he will find it moving among the fixed stars, and approaching nearer and nearer to the more eastern ones; in a year's time it will complete its revolution, and return to the same place again.

He will find seven of these bodies which revolve round the sun, to each of which he will assign a name, calling the swiftest MERCURY, denominating the others in order, according to their velocities, as VENUS, then the EARTH, and

afterwards MARS, JUPITER, SATURN, and the GEORGIUM SIDUS.

Proceeding with attention in thus exploring and examining the heavens, he will perceive that the earth is always accompanied by a small star, Jupiter by four, Saturn by five, and the Georgium Sidus by two: these sometimes precede, at others follow; now pass before, and then behind the planets they respectively attend. These small bodies he will call SECONDARY PLANETS, SATELLITES, OR MOONS.

The observer by remarking the exact time when each planet passes over some fixed star, and the time they employ from their setting out, to their return to the same star again, will find the times elapsing between each successive return of the same planet to the same star, to be equal; and he would say, that the several planets describe circles in different periods; but that each of them always completes it's own circle in the same space of time.

He will further observe, that there are certain bodies, which at their first appearance are small, obscure, ill-defined, and that move very slow, but which afterwards increase in magnitude,
5 light,

light, and velocity, until they arrive at a certain size, when they lose these properties, and diminish in the same manner as they before augmented, and at last disappear. To these bodies, which he will find in all the regions of the heavens, moving in different directions, he will give the name of COMETS.

OF THE PATHS OF THE PLANETS.

Our observer will take notice, that the planets run successively through those constellations which he has denominated, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces; and that they never move out of a certain space, or zone, of the heavens, which he will call the ZODIAC.

He will find, by proceeding in his observation, that the orbits of the planets are not all in the same plane, but that they cross each other in different parts of the heavens; so that if he makes the orbit of any planet a standard, and considers it as having no obliquity, he would judge the paths of all the rest to be inclined to it; each planet having one half of it's path on one side, and the other half on the opposite side of

the standard path, or orbit. Astronomers generally assume the earth's orbit, as the standard from which to compute the inclination of the others, and call it the ECLIPTIC. The points where the orbits intersect each other, are called the NODES.

The inclination of the orbits to each other, may be rendered more familiar to the imagination,* by taking as many hoops as there are planets, with a wire thrust through each, and thereby joined to that hoop which represents the ecliptic; the other hoops may be then set more or less obliquely, to the representative of the ecliptic.

The several orbits do not cross or intersect the ecliptic in the same point, or at the same angles; but their nodes, or intersections, are at different parts of the ecliptic.

It should, however, be observed here, that in speaking of the orbits of the planets, nothing more is meant by this term, than the paths they pass through in the open space in which they move, and in which they are retained by a celestial but continuous mechanism.

OF

* Dr. Watts's Astronomy.

OF THE MOTION OF THE PLANETS ROUND
THEIR AXIS.

By attentively considering, with a telescope, the surface of the primary planets, our solar observer will find, that some parts, or SPOTS, are more obscure than others. By continued observation he will find, that these spots change their places, and move from one side of the planet to the other; then disappear for a certain space of time; after which, they again, for a while, become visible on the side where they were first seen, always continuing the same motion nearly in an uniform manner.

The distance between the spots grows wider as they advance from the edge towards the middle of the planet, and then grows narrow again as they pass from the middle to the other edge. The time they are seen on the planet's disk, is somewhat less than the time of their disappearance.

From these circumstances he will conclude, first, that these spots adhere to the body of the planet, and that each planet is a globe turning on it's axis, and has consequently two motions, one whereby it is moved round it's axis in a short time, the other by which it revolves round the

fun. These motions may be easily conceived, by only imagining a small ball to roll round a large sphere. The first of these motions, or that of a planet round it's axis, is called the DIURNAL MOTION ; and the second, or it's revolution round the sun, is called the ANNUAL MOTION.

The tutor may in some measure realize to his pupil the foregoing heliocentric phænomena, by plate I. fig. 1, of the solar system ; or still much better, by means of a planetarium : for by supposing himself on the brass ball which represents the sun, he will see that all the planets move round him in beautiful and harmonious order ; on account of their distance, he will refer their motions to the fixed stars ; he will see how readily the periods of their revolutions are discovered, by observing the time that elapses between their setting out from any fixed point, or star, and their returning to the same again. He will also see, that if the paths of the planets were in one plane, as in the instrument, they would all be transferred to one circle in the heavens.

When he understands these particulars, the tutor may then proceed to shew him that these motions, which are so regular when viewed from
the

the sun, become intricate and perplexed when viewed from the earth; and infer from thence, that whenever we “examine the works of the Deity at a proper point of distance, so as to take in the whole of his design, we see nothing but uniformity, beauty, and precision.” Thus the heavens present us with a plan, which, though inexpressibly magnificent, is yet regular beyond the power of invention.



E S S A Y I.

P A R T II.

E S S A Y I.

P A R T II.

OF THE PHÆNOMENA OF THE HEAVENS, AS
SEEN FROM THE EARTH.

THE various appearances of the celestial bodies, as seen from the earth, are the facts which lay the foundation of all astronomical knowledge. To account for, and explain them, is it's principal business: a true idea of these phænomena is therefore a necessary step to a knowledge of astronomy.

OF THE APPARENT MOTION OF THE SUN.

The first and most obvious phænomenon is the daily rising of the sun in the east, and his setting in the west; after which the moon and stars appear, still keeping the same westerly course, till we lose sight of them altogether.

This

This cannot be long observed, before we must also perceive, that neither the sun nor moon always rise exactly at the same point of the heavens. If we commence our observations of the sun, for instance, in the beginning of March, we shall find him appear to rise more to the northward every day, to continue longer above the horizon, to be more vertical, or higher, at mid-day; this continues till towards the end of June, when he moves backward in the same manner, and continues this retrograde motion till near the end of December, when it begins to move forwards, and so on.

It is this change in the sun's place, that occasions him to rise and set in different parts of the horizon, at different times of the year. It is from hence that his height is so much greater in summer, than in winter. In a word, the change of the sun's place in the heavens is the cause of the different length in the days and nights, and the vicissitudes of the seasons.

As the knowledge of the sun's apparent motion is of great importance, and a proper conception of it absolutely necessary, in order to form a true idea of the phænomena of the heavens, the reader will excuse my dwelling something longer upon it.

it. If on an evening we take notice of some fixed star near the place where the sun sets, and observe it for several successive evenings, we shall find that it approaches the sun from day to day, till at last it will disappear, being effaced by his light, though but a few days before it was at a sufficient distance from him. That it is the sun which approaches the stars, and not the stars the sun, is plain, for this reason; the stars always rise and set every day at the same points of the horizon, opposite to the same terrestrial objects, and are always at the same distance from each other; whereas the sun is continually changing both the place of it's rising and setting, and it's distance from the stars.

The sun advances nearly one degree every day, moving from west to east; so that in 365 days we see the same star near the setting sun, as was observed to be near him on the same day in the preceding year. In other words, the sun has returned to the place from whence he set out, or made what we call his annual revolution.

We cannot indeed observe the sun's motion among the fixed stars immediately, on account of the brightness of his light, which prevents our seeing those stars that are in his neighbourhood; but

but we can observe the instant of his coming to the meridian, and his meridional altitude; we can also compute what point of the starry heaven comes to the same meridian, at the same time, and with the same altitude. The sun must be at that point of the starry heavens thus discovered. Or we can observe that point in the heavens, which comes to the meridian at midnight, with a declination as far from the equator on one side, as the sun's is on the other side; and it is evident, the sun must be in that part of the heavens, which is diametrically opposite to this point. By either of these methods we can ascertain a series of points in the heavens, through which the sun passes, forming a circle called the ECLIPTIC.*

OF THE APPARENT PHÆNOMENA OF THE MOON.

The motion of the moon through the heavens, and her appearance therein, are still more remarkable than those of the sun.

At the new moon, or when she first becomes visible, she is seen in the western part of the heavens, at no great distance from the sun. She
increases

* The conformity of this definition of the ecliptic, with that given in page 19, will be seen hereafter.

increases every night in size, and removes to a greater distance from the sun, till at last she appears in the eastern part of the horizon, when the sun is disappearing in the western. After this, she gradually removes further and further eastward, till at last she seems to approach the sun as nearly in the east as she did before in the west, and rises a little before him in the morning; whereas in the first part of her course she set in the west, long after him. All these different appearances happen in the space of a month; after which they re-commence in the same manner.

There is sometimes an irregularity in these appearances, particularly in harvest-time, when the moon appears for several days to be stationary in the heavens, and to preserve nearly the same distance from the sun; in consequence of which, she rises at that season of the year nearly at the same hour for several nights.

OF THE APPARENT MOTION OF THE STARS.

In contemplating the stars, it is observed that some among them have the singular property of neither rising in the east, nor setting in the west; but seem to turn round one immoveable point,
near

near which is placed a single star, called the **POLE**,
or **POLE STAR**.

This point is more or less elevated, according to the part of the earth from which it is viewed. Thus to the inhabitants of Lapland it is much more vertical, or elevated above the horizon, than with us : we see it more elevated than the inhabitants of Spain : and these again see it more elevated than those of Barbary. By continually travelling southward, we should at last see the pole star depressed to the horizon, and the other pole would appear in the south part of the horizon, round which the stars in that part would revolve. There is, however, no star in the southern hemisphere so near the pole, as that in the northern hemisphere. Supposing us still to travel southward, the north pole would entirely disappear, and the whole hemisphere would seem to turn round a single point in the south, as the northern hemisphere appears to turn round the pole star.

The general appearance, therefore, of the starry heavens, is that of a vast concave sphere turning round two fixed points (diametrically opposite to each other, the one in the north, the other in the south) once in twenty-four hours.

Hence

Hence it is that the stars, though they keep the same relative places with respect to each other, yet change their situation very sensibly with respect to the horizon; some rising above, others descending below it; some that were invisible, now becoming visible; while, on the other hand, many are disappearing. Some never descend below the horizon; although as they turn round, they are sometimes nearer to, at others further from it, describing whole circles about a point above it. If the observer turns himself round, he will find some stars rise only as it were to set again; many describing small arcs, and others larger ones.

THE APPEARANCES OF THE PLANETS.

Besides the fixed stars, there are other bodies in the heavens, which are continually changing their places, both with respect to the stars, and one another; these are called PLANETS.

They move among the signs of the zodiac, never departing far from the ecliptic.

Their apparent motion is very irregular, confused, and perplexed; sometimes they appear as

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going

going forwards, sometimes backwards, and at others are stationary.

MERCURY emits a bright white light, but keeps so near the sun, that he is very seldom visible; and when he does make his appearance, his motion towards the sun is so swift, that he can only be discerned for a short time. He appears a little after sun-set, and again a little before sun-rise.

VENUS is the most beautiful star in the heavens, known by the names of the morning and evening star. She also, like Mercury, keeps near the sun, though she recedes from him much further. She, like him, is never seen in the eastern quarter of the heavens, when the sun is in the western; but always either attends him in the evening, or gives notice of his approach in the morning.

MARS is of a red fiery colour, giving a much duller light than Venus, though he sometimes appears almost equal to her in size. He is not subject to the same limitations in his motions as Venus and Mercury, but appears sometimes very near the sun, at others at a greater distance from him,

him, rising when the sun sets, or setting when he rises.

JUPITER and SATURN likewise often appear at great distances from the sun. The former shines with a bright light, the latter with a pale faint one. The motion of Saturn among the fixed stars is so slow, that unless carefully observed, and that for some time, he will not be thought to move at all.

The GEORGIUM SIDUS cannot be perceived without the assistance of a telescope.

From the preceding observations, any person may easily learn to distinguish all the planets. If after sun-set he sees a planet nearer the east than the west, he may conclude that it is neither Mercury nor Venus; and may determine whether it is Saturn, Jupiter, or Mars, by the colour and light; by which, also, he may distinguish between Venus and Mercury.

That the light of each planet has it's peculiar tinge; and that there are certain fixed stars that have the same tints, was known to the Chaldeans. It is an observation best verified in those countries, where the air is clearest.

Besides the motions which we observe in all the planets, their apparent magnitudes are very different, at different times. Every one must have observed, that Venus, though she constantly appears with great splendor, is not always of the same size; but this difference of magnitude is most conspicuous in Mars, it is remarkable in Jupiter, but less so in Saturn and Mercury.

The only phænomena visible to the unassisted sight, besides those already described, are those unexpected obscurations of the sun and moon, called ECLIPSES, of which we shall hereafter speak more particularly.

We have now described those appearances, which are the most striking to every person who has paid the least attention to what is passing over his head. The tutor would do well in this place, to bring his pupil acquainted with these appearances, and then to explain them to him by the globe, or some other instrument. It would not be amiss, if he were now to instruct him by practical observations, and shew him, by a small quadrant, how to measure the elevation of the stars, &c. always remembering that young minds are ever active in search of impressions from external objects; and that these are more

permanent than those made by words: in the former the mind energizes, and is brought into action; in the latter, it is in a great degree passive.



E S S A Y I.

P A R T III.

E S S A Y I.

P A R T III.

OF THE COPERNICAN, OR SOLAR SYSTEM.

AFTER having stated what would be the appearances of the heavenly bodies, if we were placed at the center of the system, and then given a general view of their phænomena, as seen from the earth; it will now be proper to shew how the irregularities that are discovered in one situation, are to be reconciled with the harmony and order that would be visible if they were to be seen from the other; or in other words, to shew why the motions of the planets appear to us so different from what they really are.

One of the ends for which man was formed, is to correct appearances and errors, by the investigation of truth: whoever considers him attentively, from infancy to manhood, and from
manhood

manhood to old age, will find him ever busy in endeavouring to attain some reality, to supply the place of the false appearances, by which he has hitherto been deceived.

It is the business of the present part of this essay, to correct the errors arising from appearances, and to point out truth by a brief detail of the principal parts of the Copernican system, which is now universally received, because it rationally accounts for, and accords with the phænomena of the heavens.

“ At the appointed time, when it pleased the supreme dispenser of every good gift to restore light to a bewildered world, and more particularly to manifest his wisdom in the simplicity, as well as in the grandeur of his works, he opened the glorious scene with a revival of sound astronomy ;”* and raised up Copernicus to dispel the darkness in which it was then involved.

The Copernican system consists of the sun, seven primary, twelve secondary planets, and the comets.

The

* Pringle's Six Discourses to the Royal Society.

The seven planets, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, and the Georgium Sidus, move round the sun,* in orbits included one within the other, and in the order here used in mentioning their names, Mercury being that which is nearest the sun.

These seven, which revolve round the sun as their center, are called PRIMARY PLANETS.

The twelve small planets revolve round the primary ones as a center, and are at the same time carried round the sun with them; they are therefore called SECONDARY PLANETS, MOONS, or SATELLITES.

The Georgium Sidus is attended by two moons, Saturn by five, Jupiter by four, and the Earth by one; all of these, excepting the last, are invisible to us, on account of the smallness of their size, and the greatness of their distance from us.

Mercury and Venus being within the Earth's orbit, are called INFERIOR PLANETS; but Mars, Jupiter,

* The sun is not absolutely at rest, being subject to a small degree of motion, which is considered in larger works on astronomy.

Jupiter, Saturn, and the Georgium Sidus, being without it, are called SUPERIOR PLANETS.

The orbits of all the planets are elliptical ; but as the principal phænomena of the Copernican system may be satisfactorily illustrated, by considering them as circular, the latter supposition is usually adopted in giving a general idea of the disposition and motion of the heavenly bodies.

It is clear, from a great variety of proofs, that the astronomers of antiquity were acquainted with the true solar system, as revived by Copernicus. It was the universal doctrine of the Pythagorean school, and is clearly marked out as such by Aristotle: for these, says he, assert that fire is in the midst of the world, and that the earth is one of the heavenly bodies. He afterwards speaks of a set of men, who held a system essentially similar to that of the modern semitychonic. Eudemus, in his history of astronomy, as cited by Anatolius, says, that Anaximander was the first who discovered the earth to be one of the heavenly bodies, and to move round the center of the world. Aristarchus held that the earth is carried round the sun, in the circumference of a circle, of which the sun itself is the center ; and that the sphere of the fixed stars is so immense,

immense, that the circle of the earth's annual orbit bears no greater proportion to it, than the center of any sphere bears to it's whole surface. Philolaus, and others, declared the motion of the sun, round about the earth, to be only apparent. They saw and felt the importance of his globe over our's, and supposing it's influence to extend to much larger bounds than that of the earth, they placed it in the center of the universe. Among the Romans, we find that Numa built a temple to represent, as Plutarch interprets it,* the system of the heavens, with a sacred fire in the center of it.† Thus also in the Jewish tabernacle, the seven lights had a reference to the seven chief lights of the heavens. Hence also the heavens are called in sacred writ the tabernacle of the sun; the whole of our system dwelling within his influence. The foregoing citations are, we presume, sufficient to shew that the ancients were not ignorant of the true solar system. Those that want further information on this head, may consult the notes to Sydenham's translation of the Rivals of Plato, Duten's inquiries

* Plutarch in Vita Numæ.

† Focum Vestæ virginibus colendum dedit, UT AD SIMILITUDINEM CÆLESTIUM SIDERUM custos imperii flamma vigilaret. Flor. Hist.

ries into the origin of the discoveries attributed to the moderns; Jones's essay on the first principles of natural philosophy; Baillie *histoire de l'astronomie ancienne*. But laying these authorities aside, there are direct proofs to shew, that the most ancient sages could not be ignorant of the true system; these, however, must be left to some other occasion.

We are greatly indebted to Copernicus for the revival of this system, and being bold enough to avow it, though it was entirely opposed to the prejudices of the age he lived in. In praising of Copernicus, let us not, however, endeavour to do away the well-earned fame of Ptolemy; his system, though erroneous, was ingenious; with it the world was content for many ages. It was then considered as founded upon invincible demonstration, as a sacred truth, that could not be weakened by the powers of controversy, or shaken by the fluctuations of opinion. Being in possession of higher truth, we should not speak degradingly of those who preceded us. If the ground we stand on be firm, it will not need support from the empty boastings of declamation, the authority of names, or the contemptuous sneers of an affected disdain: the writings of modern philosophers furnish but too many instances

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ces of the high opinion they entertain of their own knowledge, and their contempt of those who differ from them.

Let the young pupil be cautioned not to confine the idea of bigotry to the superstitious zealots of religion ; for he will find as much attachment to trifles, as much blind prejudice, and as little love to truth for truth's sake, among those who are called philosophers, as among the most inveterate sectarians, or the wildest fanatics.

Let him, therefore, early learn to distinguish the different degrees of evidence, of which each subject is capable ; but above all, let him studiously avoid the improper conjunction of the demonstrative evidence of one science, with the bare probability, or unfounded assertions in another ; lest, like those who have gone before him, he should call that demonstrated, which is often not even probable.

Before we enter into a description of the system, it may be necessary to define what is meant by the axis of a planet ; lest the pupil should conceive them to turn on such material axes, as are used in the machines which are contrived to represent the planetary system.

The

The AXIS OF A PLANET is a line conceived to be drawn through it's center, and about which it continually turns, in the course of it's revolution round the sun : the extremities of this line terminate in opposite points of the surface of the planet, and are called it's POLES ; that which points towards the northern part of the heaven, is called the NORTH POLE ; that which points towards the southern, the SOUTH POLE.

A ball whirled from the hand into the open air, turns round upon a line within itself, while it is moving forward ; such a line as this is meant, when we speak of the axis of a planet.

Fig. 1, plate I. represents the solar system, whercin \odot denotes the sun ; A B the circle which the nearest planet, Mercury, describes in moving round it ; C D that in which Venus moves ; F G the orbit of the earth ; H K that of Mars ; I N that of Jupiter ; O P that of Saturn ; and Q R that of the Georgium Sidus ; beyond this are the starry heavens.

The sun and the planets are sometimes expressed by marks or characters, instead of writing their names at length. The characters are as follow :

follow: ☉ the sun, ☿ Mercury, ♀ Venus, ⊕ the earth, ♂ Mars, ♃ Jupiter, ♄ Saturn.

OF THE SUN.

The sun is the center of the system, round which the rest of the planets revolve. It is the first and greatest object of astronomical knowledge, and is alone enough to stamp a value on the science, to which the study of it belongs.

The sun is the parent of the seasons; day and night, summer and winter, are among its surprising effects. All the vegetable creation are the offspring of its beams; our own lives are supported by its influence. Nature revives, and puts on a new face, when it approaches nearer to us in spring; and sinks into a temporary death at his departure from us in the winter.

Hence it was, with propriety, called by the ancients COR CÆLI, the heart of heaven; for as the heart is the center of the animal system, so is the sun the center of our universe. As the heart is the fountain of the blood, and the center of heat and motion; so is the sun the life and heat of the world, and the first mover of the mundane system. When the heart ceases to beat, the cir-

cuit of life is at an end ; and if the sun should cease to act, a total stagnation would take place throughout the whole frame of nature.

“ By his magnetic beam he gently warms
The universe, and to each inward part,
With gentle penetration, though unseen,
Shoots invifible virtue.”

The sun is placed near the center of the orbits of all the planets, and turns round his axis in twenty-five days. It is inclined to the ecliptic in an angle of eight degrees.

Those who are not accustomed to astronomical calculation, will be surprized at the real magnitude of this luminary ; which, on account of it's distance from us, appears to the eye not much larger than the moon, which is only an attendant on this earth. When looking at the sun, they are viewing a globe, whose diameter is 890,000 English miles, whose surface contains 2,488,461,360,000 square miles ; whereas the earth is not more in diameter than 7950 miles : so that the sun is about 1,392,500 times bigger than the earth. It is reckoned to be $539\frac{1}{2}$ times bigger than all the planets put together. Thus as it is the fountain of light and heat to all the planets, so it also far surpasses them in it's bulk.

If the sun were every where equally bright, his rotation on his axis would not be perceptible ; but by means of the spots, which are visible on his pure and lucid surface, we are enabled to discover this motion.

When a spherical body is near enough to appear of it's true figure, it is the shading upon the different parts of it's surface that causes it to appear of that figure to our eyes : for as a flat circular piece of board, when it is properly shaded by painting, will look like a spherical body ; so the spherical body appears of it's true shape, for the same reason that the plane board, in the present instance, appears spherical. But if the sphere is at a great distance, this difference of shading cannot be discerned by the eye, and consequently the sphere will no longer appear of it's true shape ; the shading is then lost, and it seems like a flat circle.

It is thus with the sun ; it appears to us like a bright flat circle, which flat circle is termed the SUN'S DISK. By the assistance of telescopes, dark spots have been observed on this disk, and found to have a motion from east to west ; their velocity is greater when they are at the center, than when they are near the limb. They are seen

first on one extremity, and by degrees come forwards towards the middle, and so pass on, till they reach the opposite edge; they then disappear; and after they have lain hid about the same time that they continued visible, they will appear again as at first. By this motion, we discover not only the time the sun employs in turning round his axis, but also the inclination of it's axis to the plane of the ecliptic.

The page of history informs us, that there have been periods, when the sun has wanted of it's accustomed brightness, shone with a dim and obscure light for the space of a whole year. This obscurity has been supposed to arise from his surface being at those times covered with spots. Spots have been seen, that were much larger than the earth.

The sun is supposed to have an atmosphere round it, which occasions that appearance which is termed the ZODIACAL LIGHT. This light is seen at some seasons of the year, either a little after sun set, or a little before sun-rise. It is faintly bright, and of a whitish colour, resembling the milky way. In the morning it becomes brighter and larger, as it rises above the horizon, till the approach of day, which diminishes it's splendor,

splendor, and renders it at last invisible. It's figure, is that of a flat or lenticular spheroid, seen in profile. The direction of it's longer axis coincides with the plane of the sun's equator. But it's length is subject to great variation, so that the distance of it's summit from the sun, varies from 45 to 120 degrees. It is seen to the best advantage about the solstices. It was first described and named by Cassini, in 1683; it was noticed by Mr. Childrey, about the year 1650.

OF THE INFERIOR PLANETS, MERCURY AND VENUS.

OF MERCURY. ☿

Of all the planets, Mercury is the least; at the same time, it is that which is nearest the sun. It is from his proximity to this globe of light, that he is so seldom within the sphere of our observation, being lost in the splendor of the solar brightness. It is oftener seen in those parts of the world, which are more southward than that which we inhabit; and oftener to us than to those who live nearer the north pole; for the more oblique the sphere is, the less is the planet's elevation above the horizon.

Mercury never removes but a few degrees from the sun. The measure of a planet's separation, or distance, from the sun, is called it's **ELONGATION**. His greatest elongation is little more than twenty-eight degrees, or about as far as the moon appears to be from the sun, the second day after new moon. In some of it's revolutions, the elongation is not more than eighteen degrees.

Mercury is computed to be at 36,841,468 miles from the sun, and to revolve round him in 87 days, $23\frac{1}{2}$ hours, which is the measure of it's year, about one-fourth of our's. As from the nearness of this planet to the sun, we neither know the time it revolves round it's axis, nor the inclination of that axis to the plane of it's orbit, we are necessarily ignorant of the length of it's day and night, or the variety of seasons it may be liable to. Mercury is 3000 miles in diameter, and therefore contains in surface 28,274,400 square miles. Large as Mercury, when thus considered, appears to be, it is but an atom, when compared with Jupiter, whose diameter is 94000 miles.

Mercury is supposed to move at the rate of $109,699\frac{16}{100}$ miles per hour. The sun is

26,109,963 times as big as Mercury ; so that it would appear to the inhabitants of Mercury nearly three times larger than it does to us ; and it's disk, or face, about seven times the size we see it. As the other five planets are above Mercury, their phænomena will be nearly the same to it as to us. Venus and the earth, when in opposition to the sun, will shine with full orbs, and afford a brilliant appearance to the Mercurian spectator.

Mercury, like the moon, changes it's phases, according to it's several positions with respect to the sun and earth. He never appears quite round or full to us, because his enlightened side is never turned directly towards us, except when he is so near the sun, as to become invisible. The times for making the most favourable observations on this planet, are, when it passes before the sun, and is seen traversing his disk, in the form of a black spot. This happens in it's lower conjunction, at a particular situation of it's nodes ; which leads us to mention their place in the ecliptic.

The angle formed by the inclination of the orbit of Mercury with the plane of the ecliptic, is $6^{\circ} 54$ min. ; the node from which Mercury ascends northward, above the plane of the eclip-

tic, is in the 14th degree of Taurus; the opposite one in the 14th degree of Scorpio. The earth is in these points on the 6th of November, and the 4th of May. If Mercury, at his inferior conjunction, comes to either of his nodes about these times, he will appear to TRANSIT over the disk of the sun. But in all other parts of his orbit his conjunctions are invisible, because he either goes above or below the sun.

OF VENUS. ♀

Venus is the brightest and largest, to appearance, of all the planets, distinguished from them all by a superiority of lustre; her light is of a white colour, and so considerable, that in a dusky place she projects a sensible shade. Milton takes notice of her superior lustre, in describing his evening in Paradise, thus:

“Now came still Ev’ning on, and Twilight grey
Had in her sober liv’ry all things clad;

Silence was pleas’d: NOW GLOW’D THE FIRMA-
MENT

WITH LIVING SAPPHIRES: HESPERUS, THAT LED
THE STARRY HOST, RODE BRIGHTEST; till the
moon,

Rising in clouded majesty, at length,

Apparent

Apparent queen, unveil'd her peerless light,
And o'er the dark her silver mantle threw."

The diameter of Venus is 9330 miles; she contains 273,472,824 square miles; her distance from the sun is 68,891,486 miles; she goes round the sun in 224 days, 17 hours, moving at the rate of $80,295\frac{24}{100}$ miles per hour. It's axis is inclined to the plane of it's orbit, in an angle of 75 degrees. Her orbit makes an angle of $3^{\circ} 20$ min. with the ecliptic; one node is at the 14th degree of Gemini, the other in Sagittarius. Her motion round her axis has been fixed by some at 23 hours; by others at above 24 days. She, like Mercury, constantly attends the sun, never departing from him above 47 or 48 degrees. Like Mercury, she is never seen at midnight, or in opposition to the sun, being visible only for three or four hours in the morning, or evening, according as she is before or after the sun.

One would not imagine that this planet, which appears so much superior to Saturn in the heavens, is so inconsiderable when compared to it; for the diameter of Saturn is 78,000 miles; while, on the other hand, one would scarce imagine
that

that Venus, which appears but as a lucid spangle in the heavens, was so large a globe as she truly is, her diameter being 9330 miles. It is the distance which produces these effects; which gives and takes away the magnitude of things.

When this planet is in that part of it's orbit which is west of the sun, that is, from her inferior conjunction to her superior, she rises before him in the morning, and is called PHOSPHORUS, or LUCIFER, or the MORNING STAR. When she appears east of the sun, that is, from her superior conjunction to her inferior, she sets in the evening after him; or in other words, shines in the evening after he sets, and is called HESPERUS, or VESPER, or the EVENING STAR.

The inhabitants of Venus will see the planet Mercury always accompanying the sun; and he will be to them, by turns, an evening or a morning star, as Venus is to us. To the same inhabitants, the sun will appear almost twice as large as he does to us.

Venus, when viewed through a telescope, is seldom seen to shine with a full face; but has phases, just like the moon, from the fine thin crescent to the enlightened hemisphere. Her
illu-

illuminated part is constantly turned towards the sun ; hence it's horns are turned towards the east when it is a morning star, and towards the west when it is an evening star.

We are told, that, when Copernicus first published his account of the solar system, it was objected to him that it could not be true, because if it was, the inferior planets must have different phases, according to their different situation with respect to the sun and earth ; whereas they always appear round to us. The answer said to be made by him, is, that they appear round to the eye by reason of their distance ; but if we could have a nearer, or more distinct view of them, we should see in them the same phases we do in the moon. The invention of telescopes is said to have verified this prediction of Copernicus.

But it is neither probable, that a defender of the Ptolemaic system should make such an objection, or Copernicus such an answer ; since in the Ptolemaic, as well as in the Copernican system, the shape of these planets ought to change, just as the moon does ; consequently, the mere change of shape in the inferior planets is an argument, which, in the common way of urging it,

it, proves nothing at all as to the truth or falshood of the Copernican system.

If, besides the changes of shape made in the inferior planets, we consider the situation of the planets with respect to the sun, when these changes happen; this, indeed, will shew us, that the Ptolemaic system is false,* as will be seen in a subsequent part of this essay.

Taking the times in which the planets move round the sun, for the length of their year; and the times of their turning round their axes, for the length of their days and nights together; and assuming, as true, the observations of Bianchini, relative to the rotation of Venus round her axis; we may say, that a day and a night in Venus is as long as $23\frac{1}{2}$ days and nights with us; her axis inclines 75 degrees from the axis of her orbit, on which account the length of her days and nights differ much more in proportion, and the variation of her seasons is greater than those of our earth. She very seldom has the forenoon and afternoon of the same day of an equal length. At her equator she has the four seasons twice every year, with other peculiarities, which are enumerated in larger treatises on this subject.

Venus

* Rutherford's System of Natural Philosophy, vol. 2, p. 781.

Venus is sometimes seen passing over the disk of the sun, as a round dark spot. These appearances, which are called transits, happen very seldom; there have been two within these few years, the one in June, 1761, the other in June, 1769; the next will be in the year 1874.

OF THE EARTH. \oplus

The next planet that comes before us, is the earth that we inhabit; small as it really is when compared to some of the other planets, it is to us of the highest importance: we wish only to attain knowledge of the others, that we may find out their relation to this, and from thence learn our connection with the universe at large. But when viewed with an eye to eternity, it's value to us is heightened in a manner that exceeds expression, and surpasses all the powers of the human mind. He alone can form some idea of it, who in the regions of celestial bliss is become a partaker of the length and breadth, the depth and height, of divine love.

The orbit of the earth is placed between those of Venus and Mars. The diameter of the earth is 7970 miles; it's surface contains 199,557,259 square miles; it's distance from the sun is

95,173,000 miles, and goes round him in a year, moving at the rate of $68,243\frac{24}{100}$ miles per hour.

It turns round it's axis from WEST TO EAST, in twenty-four hours, which occasions the apparent diurnal motion of the sun, and all the heavenly bodies round it, from EAST TO WEST in the same time ; it is, of course, the cause of their rising and setting, of day and night.

The axis of the earth is inclined $23\frac{1}{2}$ degrees to the plane of it's orbit, and keeps in a direction parallel to itself, throughout it's annual course, which causes the returns of spring and summer, autumn and winter. Thus his diurnal motion gives us the grateful vicissitude of night and day, and his annual motion the regular succession of seasons.

OF THE MOON. ☾

Next to the sun, the moon is the most splendid and shining globe in the heavens, the satellite, or inseparable companion of the earth. By dissipating, in some measure, the darkness and horrors of the night ; by her various appearances, subdividing the years into months ; by regulating the flux and reflux of the sea ; she not
only

only becomes a pleasing, but a welcome object ; an object affording much for speculation to the contemplative mind, of real use to the navigator, the traveller, and the husbandman.

That the moon appears so much larger than the other planets, is owing to her vicinity to us ; for to a spectator in the sun she would be scarcely visible, without the assistance of a telescope. Her distance is but small from us, when compared with that of the other heavenly bodies ; for among these, the least absolute distance, when put down in numbers, will appear great, and the smallest magnitude immense.

The moon is 2180 miles in diameter ; her bulk is in proportion to the earth as 1 to $48\frac{6}{10}$; her distance from the center of the earth 240,000 miles ; she goes round her orbit in 27 days, 7 hours, 43 minutes, moving at the rate of $2299\frac{65}{100}$ miles per hour. The time in going round the earth, reckoning from change to change, is 29 days, 12 hours, 44 minutes.

Her orbit is inclined to the ecliptic, in an angle of 5 degrees, 18 minutes, cutting it in two points, which are diametrically opposite to each other ; these points are called her nodes. The

nodes have a motion westward, or contrary to the order of the signs, making a complete revolution in about nineteen years; in which time, each node returns to that point of the ecliptic whence it before receded.

While the moon is making her revolution round the heavens, she undergoes great changes in her appearance. She is sometimes on our meridian at midnight, and therefore in that part of the heavens which is opposite to the sun; in this situation she appears as a complete circle, and it is said to be FULL MOON. As she moves eastward, she becomes deficient on the west side, and in about $7\frac{1}{3}$ days comes to the meridian, at about six in the morning, having the appearance of a semicircle, with the convex side turned towards the sun; in this state, her appearance is called the HALF MOON. Moving on still eastward, she becomes more deficient on the west, and has the form of a crescent, with the convex side turned towards the sun; this crescent becomes continually more slender, till about 14 days after the full moon, she is so near the sun, that she cannot be seen, on account of his great splendor. About four days after this disappearance, she is seen in the evening, a little to the eastward of the sun, in the form of a fine crescent, with

with the convex side turned from the sun; moving still to the eastward, the crescent becomes more full; and when the moon comes to the meridian, about six in the evening, she has again the appearance of a bright semicircle; advancing still to the eastward, she becomes fuller on the east side; at last, in about $29\frac{1}{2}$ days, she is again opposite to the sun, and again full.

It frequently happens, that the moon is eclipsed when at the full; that the sun is eclipsed some time between the disappearance of the moon in the morning on the west side of the sun, and her appearance in the evening on the east side of the sun. The nature of these phænomena will be more fully considered, when we come to treat particularly of eclipses.

In every revolution of the moon about the earth, she turns once round upon her axis, and therefore presents the same face to our view; and her day and night together are as long as our lunar month. As we see only one side of the moon, we are therefore invisible to the inhabitants on the opposite side, without they take a journey to that side which is next to us, for which purpose some of them must travel more than 1500 miles.

As the moon illuminates the earth by a light reflected from the sun, she is reciprocally enlightened, but in a much greater degree, by the earth; for the surface is above 13 times greater than that of the moon; and therefore, supposing their power of reflecting light to be equal, the earth will reflect 13 times more light on the moon than she receives from it. When it is what we call new moon, we shall appear as a full moon to the Lunarians; as it increases in light to us, our's will decrease to them; in a word, our earth will exhibit to them the same phases as she does to us.

We have already observed, that from one half of the moon the earth is never seen; from the middle of the other half, it is always seen over head, turning round almost thirty times as quick as the moon does. To her inhabitants, the earth seems to be the largest body in the universe, about thirteen times as large to them, as she does to us. As the earth turns round it's axis, the several continents and islands appear to the Lunarians as so many spots, of different forms; by these spots, they may determine the time of the earth's diurnal motion; by these spots, they may, perhaps, measure their time,—they cannot have a better dial.

OF THE SUPERIOR PLANETS.

Mars, Jupiter, Saturn, and the Georgium Sidus, are called superior planets, because they are higher in the system, or farther from the center of it, than the earth is.

They exhibit several phænomena, which are very different from those of Mercury and Venus; among other things, they come to our meridian both at noon and midnight, and are never seen crossing the sun's disk.

OF MARS. ♂

Mars is the least bright and elegant of all the planets; it's orbit lies between that of the earth and Jupiter, but very distant from both. He appears of a dusky reddish hue; from the dullness of his appearance, many have conjectured that he is encompassed with a thick cloudy atmosphere.

Mars, which appears so inconsiderable in the heavens, is 5,400 miles in diameter, 91,608,956 square miles in superficial content. It's distance from the sun is 145,014,148 miles. It goes round the sun in 1 year, 321 days, 17 hours, moving at

the rate of 55,287 miles per hour. It revolves round it's axis in 24 hours, 40 minutes; it's orbit is inclined to the ecliptic, at an angle of 1 deg. 52 min.; to an inhabitant in Mars, the sun would appear one-third less in diameter than it does to us.

Mars, when in opposition to the sun, is five times nearer to us than when in conjunction. This has a very visible effect on the appearance of the planet, causing him to appear much larger at some periods than at others.

The axis of this planet is nearly at right angles to it's orbit. The time, therefore, the sun is above the horizon, or the length of the natural day, will almost, in every part, be equal to the night, or the time the sun is below the horizon. There will be very little change or variety of seasons; but places, in different latitudes, will have very different degrees of light and cold, on account of the different inclination of the sun's rays to the horizon.

A spectator in Mars will rarely, if ever, see Mercury, except when they see it passing over the sun's disk. Venus will appear to him at about the same distance from the sun, as Mercury

appears to us. The earth will appear about the size of Venus, and never above 48 degrees from the sun; and will be, by turns, a morning and evening star to the inhabitants of Mars.

OF JUPITER. 4

Jupiter is situated still higher in the system, revolving round the sun, between Mars and Saturn. It is the largest of all the planets, and easily distinguished from them by his peculiar magnitude and light. To the naked eye it appears almost as large as Venus, but not altogether so bright.

Jupiter revolves round it's axis in 9 hours, 56 minutes; round the sun in 4332 days, 12 hours, 20 minutes, or near 12 years. The disproportion of Jupiter to the earth, in size, is very great; viewing him in the heavens, we consider him as small in magnitude; whereas he is in reality 94,000 miles in diameter, and 25,759,077,600 square miles in superficial content; his distance from the sun is 494,990,976 miles; he moves at the rate of rather more than 22,101 miles per hour; his orbit is inclined to the ecliptic, at an angle of 1 deg. 20 min.

To an eye placed in Jupiter, the sun would not be a fifth part of the size he appears to us, and his disk be 25 times less. Though Jupiter be the largest of all the planets, yet it's revolution round it's axis is the swiftest. The polar axis is shorter than the equatoreal one, and his axis perpendicular to the plane of his orbit.

Jupiter, when in opposition to the sun, is much nearer the earth, than when he is in conjunction with him; at those times he appears also larger, and more luminous than at other times.

Jupiter is attended by four satellites, or moons; these are invisible to the naked eye; but through a telescope they make a beautiful appearance. As our moon turns round the earth, enlightening the nights, by reflecting the light she receives from the sun, so these also enlighten the nights of Jupiter, and move round him in different periods of time, proportioned to their several distances: and as the moon keeps company with the earth in it's annual revolution round the sun; so these accompany Jupiter in it's course round that luminary.

In speaking of the satellites, we distinguish them according to their places, into the first, the second, and so on ; by the first, we mean that which is nearest to the planet.

In Jupiter, the days and nights are of an equal length, each being about five hours long. We have already observed, that the axis of his diurnal rotation is nearly at right angles to the plane of his annual one ; and here, as far as we may reason from analogy, we may discover the footsteps of that wisdom, which is so conspicuous in all the works of the Creator : for if the axis of this planet were inclined by any considerable number of degrees, just so many degrees round each pole would, in their turn, be almost six years in darkness ; and as Jupiter is of such an amazing size, in this case immense regions of land would be uninhabitable.

The outermost of Jupiter's satellites will appear almost as big as the moon does to us ; five times the diameter, and twenty-five times the disk of the sun. The four satellites must afford a pleasing spectacle to the inhabitants of Jupiter ; for sometimes they will rise all together, sometimes be all together on the meridian, ranged one under another, besides frequent eclipses. Not-

withstanding the distance of Jupiter and his satellites from us, the eclipses thereof are of considerable use, for ascertaining with accuracy the longitude of places. From the four satellites, the inhabitants of Jupiter will have four different kinds of months, and the number of them in their year not less than 4500.

An astronomer in Jupiter will never see Mercury, Venus, the earth, or Mars; because, from the immense distance at which he is placed, they must appear to accompany the sun, and rise and set with him; but then he will have for the objects of observation, his own four moons, Saturn, his ring and satellites, and probably the Georgium Sidus.

OF SATURN. ♄

Before the discovery of the Georgium Sidus, Saturn was reckoned the most remote planet in our system; he shines but with a feeble light, less bright than Jupiter, though less ruddy than Mars. The uninformed eye imagines not, when it is directed to this little speck of light, that it is viewing a large and glorious globe, one of the most stupendous of the planets, whose diameter is 78,000 miles, whose surface contains

19,113,494,400 square miles. We need not, however, be surprized at the vast bulk of Saturn, and it's disproportion to it's appearance in the heavens; for we are to consider, that all objects decrease in their apparent magnitude, in proportion to their distance; but the distance of Saturn is immense; that of the earth from the sun is 95,173,000 miles; of Saturn, 907,956,130 miles!

The length of a planet's year, or the time of it's revolution round it's orbit, is proportioned to it's distance from the sun. Saturn goes round the sun in 29 years, 167 days, 6 hours, moving at the rate of rather more than 22,101 miles per hour. His orbit is inclined to the ecliptic, in an angle of 2° deg. 30 min.

It has not yet been ascertained by astronomical observation, whether Saturn revolves or not upon his axis: we are therefore ignorant of the length of his day, and of his night. The sun's disk will appear ninety times less to an inhabitant of Saturn, than it does to us; but notwithstanding the sun appears so small to the inhabitants of the regions of Jupiter and Saturn, the light that he will afford them is much more than would be at first supposed; and calculations have been made, from
which

which it is inferred, that the sun will afford 500 times as much light to Saturn, as the full moon to us; and 1600 times as much to Jupiter. To eyes like our's, unassisted by instruments, Jupiter and the Georgium Sidus would be the only planets seen from Saturn, to whom Jupiter would sometimes be a morning, sometimes an evening star.

There is a singular and curious appendage to the planet Saturn; a thin, broad, opaque ring, encompassing the body of that planet, without touching it, like the horizon of an artificial globe, appearing double when viewed through a good telescope. The space between the ring and the globe of Saturn, is supposed to be rather more than the breadth of the ring, and the greatest diameter of the ring to be in proportion to that of the globe, as 7 to 3; the plane of the ring is inclined to the plane of the ecliptic, in an angle of 30 degrees, and is about 21,000 miles in breadth. It puts on different appearances to us, sometimes being seen quite open, at others only as a line upon the equator. It is probable, that it will at times cast a shadow over vast regions of Saturn's body. The ring of Saturn, considered as a broad flat ring of solid matter, suspended round the body of the planet, and keeping it's place without any connection with the body, is quite different from

from all other planetary phænomena with which we are acquainted. Of the nature of this ring, various and uncertain were the conjectures of the first observers; yet they were not less perplexed, than those of the latest. Of it's use to the inhabitants of Saturn, we are equally ignorant; though there are reasons for supposing that it would appear to them as little more than a white or bright-coloured cloud. Some of the phænomena of Saturn's ring will be treated of more particularly in another part of this essay.

Saturn is not only furnished with this beautiful ring, but it has also five attendant moons.

OF THE GEORGIUM SIDUS,

From the time of Huygens and Cassini, to the discovery of the Georgium Sidus by Dr. Herschel, though the intervening space was long, though the number of astronomers was increased, though assiduity in observing was assisted by accuracy and perfection in the instruments of observation, yet no new discovery was made in the heavens, the boundaries of our system were not enlarged. The inquisitive mind naturally inquires, why, when the number that cultivated the science was increased, when the science itself was so much improved,

improved, in practical discoveries it was so deficient? A small knowledge of man will answer the question, and obviate the difficulty.

The mind of man has a natural propensity to indolence; the ardour of it's pursuits, when they are unconnected with selfish views, are soon abated, small difficulties discourage, a little inconvenience fatigues him, and his reason will soon find excuses to justify, and even applaud his weakness. In the present instance, the unmanageable length of the telescopes that were in use, and the continual exposure to the cold air of the night, were the difficulties the astronomer had to encounter with; and he soon persuaded himself, that the same effects would be produced by shorter telescopes, with equal magnifying power; herein was his mistake, and here the reason why so few discoveries have been made since the time of Cassini. A similar instance of the retrogradation of science, occurs in the history of the microscope, as I have shewn in my essays on that instrument.

The Georgium Sidus was discovered by Dr. Herschel, in the year 1781; for this discovery he obtained from the Royal Society the honorary recompence of Sir Godfrey Copley's medal. He
named

named the planet in honour of his Majesty King George III. who has taken Mr. Herschel under his patronage, and granted him an annual salary.

In so recent a discovery of a planet so distant, many particulars cannot be expected. It's year is supposed to be more than 83 siderial years; the inclination of it's orbit 43 min. 35 seconds; it's bulk to that of the earth as 4,454 to 1. It's light is of a blueish white colour, and it's brilliancy between that of the moon and Venus.

With a telescope, which magnifies about 300 times, it appears to have a very well defined visible disk; but with instruments of a smaller power it can hardly be distinguished from a fixed star, between the sixth and seventh magnitude. When the moon is absent, it may also be seen by the naked eye.

This general view of the solar system cannot, I apprehend, be better concluded than in the words of that excellent mathematician, Mr. Maclaurin.

“The view of nature, which is the immediate object of sense, is very imperfect, and of small extent;

extent ; but by the assistance of art, and the aid of reason, becomes enlarged, till it loses itself in infinity. As magnitude of every sort, abstractedly considered, is capable of being increased to infinity, and is also divisible without end ; so we find, that in nature the limits of the greatest and least dimensions of things, are actually placed at an immense distance from each other.

“ We can perceive no bounds of the vast expanse, in which natural causes operate, and fix no limit, or termination, to the universe. The objects we commonly call great, vanish, when we contemplate the vast body of the earth. The terraqueous globe itself is lost in the solar system ; the sun itself dwindles into a star ; Saturn’s vast orbit, and all the orbits of the comets, crowd into a point, when viewed from numberless places between the earth and the nearest fixed stars. Other suns kindle to illuminate other systems, where our sun’s rays are unperceived ; but they also are swallowed up in the vast expanse. When we have risen so high, as to leave all definite measures far behind us, we find ourselves no nearer to a term, or limit.

“ Our

“Our views of nature, however imperfect, serve to represent to us, in a most sensible manner, that mighty power which prevails throughout, acting with a force and efficacy that suffers no diminution from the greatest distances of space or intervals of time; and to prove that all things are ordered by infinite wisdom, and perfect goodness, scenes which should excite and animate us to correspond with the general harmony of nature.”

OF THE SHAPE OR FIGURE OF THE EARTH.

Having given a general idea of the Copernican system, and the bodies of which it is composed, it will be necessary to enlarge these ideas by a more minute description of the particular parts, which form this great whole; and to strengthen them by the force of that evidence, on which the system is founded.

We have already observed, that the appearance of the heavenly bodies is not the same to the inhabitants of various parts of the earth; that the sun, the moon, and the stars, rise and set in Greenland in a manner very different from what they do in the East-Indies, and in both places very different from what they do in England: and

and as it was natural to attribute the cause of this change in the apparent face of the heavens, to the figure of the earth, (for appearances must ever answer to the form and structure of the things) the nature of this figure was, therefore, one of the first objects of inquiry among philosophers and astronomers.

Some of the sages of antiquity concluded, that the earth must necessarily be of a spherical figure, because that figure was, on many accounts, the most convenient for the earth, as an habitable world : they also argued, that this figure was the most natural, because any body exposed to forces, which tend to one common center, as is the case with the earth, would necessarily assume a round figure. The assent, however, of the philosopher to this truth, was not determined by speculative reasoning ; but on evidence, derived from facts and actual observation. From these I shall select those arguments, that I think will have the greatest weight with young minds.

It is known, from the laws of optics and perspective, that if any body, in all situations, and under all circumstances, projects a circular shadow, that body must be a globe.

It is also known, that eclipses of the moon are caused by the shadow of the earth.

And we find, that whether the shadow be projected towards the east, or the west, the north, or the south, under every circumstance it is circular; the body, therefore, that casts the shadow, which is the earth, must be of a globular figure.

We shall obtain another convincing proof of the globular shape of the earth, by inquiring in what manner a person standing upon the coast of the sea, and waiting for a vessel which he knows is to arrive, sees that vessel.

We shall find, that he first of all, and at the greatest distance, sees the top of the mast rising out of the water; and the appearance is, as if the ship was swallowed up in the water. As he continues to observe the object, more and more of the mast appears; at length he begins to see the top of the deck, and by degrees the whole body of the vessel. On the other hand, if the ship be departing from us, we first lose sight of the hull, at a greater distance the main sails disappear, and at a still greater the top-sail. But if the surface of the sea were a plane, the body of the ship, being the largest part of it, would be

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seen

seen first, and from the greatest distance, and the masts would not be visible till it came nearer.

To render this, if possible, still clearer, let us consider two ships meeting at sea, the top-mast of each are the parts first discovered by both, the hull, &c. being concealed by the convexity of the globe which rises between them. The ships may, in this instance, be resembled to two men, who approach each other on the opposite sides of a hill; their heads will first be seen, and gradually, as they approach, the body will come entirely in view.

This truth is fully evinced by the following consideration; that ships have sailed round the earth, have gone out to the westward, and have come home from the eastward; or in other words, the ships have kept the same course, and yet returned from the opposite side into the harbour whence they first sailed. Now we are certain that this could not be the case, if the earth were a plane; for then a person, who should set out from any one point, and go on straight forward, without stopping, would be continually going further from the point from which he set out. This argument may be much elucidated, by referring the pupil to a terrestrial globe, on
which

which he may follow the tracks of an Anson and a Cook round the globe.

Fig. 1 and 2, plate II. are illustrations of the foregoing principles. Fig. 1, shews that if the earth was a plane, the whole of a ship would be seen at once, however distant from the spectator, and that whether he was placed at the top or bottom of a hill. From fig. 2, it appears, that the rotundity of the earth, represented by the circle A B C, conceals the lower part of the ship *d*, while the top-mast is still visible; and that it is not till the ship comes to *e* that the whole of it is visible.

Observe any star near the northern part of the horizon, and if you travel to the south, it will seem to dip farther and farther downwards, till by proceeding, it will descend entirely out of sight. In the mean time, the stars to the southward of our traveller will seem to rise higher and higher. The contrary appearances would happen, if he went to the northward. This proves that the earth is not a plane surface, but a curve in the direction south and north. By an observation nearly similar to this, the traveller may prove the curvature of the earth, in an east and west direction.

The globular figure of the earth may be also inferred from the operation of levelling, or the art of conveying water from one place to another : for in this process, it is found necessary to make an allowance between the true and apparent level ; or in other words, for the figure of the earth. For the true level is not a strait line, but a curve, which falls below the strait line, about eight inches in a mile, four times eight in two miles, nine times eight in three miles, sixteen times eight in four miles, always increasing as the square of the distance.

What the earth loses of it's sphericity by mountains and vallies, is very inconsiderable ; the highest eminence bearing so little proportion to it's bulk, as to be scarcely equivalent to the minutest protuberance on the surface of a lemon.

It is proper, however, to acquaint the young pupil, that though we call our earth a globe, and that when speaking in general terms, it may be considered as such ; yet, in the strictness of truth, it must be observed, that it is not exactly and perfectly spherical, but is what we term an oblate spheroid, flattened a little towards the poles, and swelling at the equator ; the equatorial diameter being about thirty-four miles longer than the
diameter

diameter from pole to pole. This difference bears, however, too small a proportion to the diameter, to be represented on globes.

OF THE DIURNAL MOTION OF THE EARTH.

Young people generally find some difficulty in conceiving that the earth moves ; the more so, because, in order to allow it, they must give up, in a great measure, the evidence of their exterior senses, of which the impressions are with them exceeding strong and lively. It will, therefore, be necessary for the tutor to prove to them, that they can by no means infer that the earth is at rest, because it appears so to them ; and he should convince them, by a variety of facts, that reason was given to correct the fallacies of the senses. To this end we shall here point out some instances, where apparent motion is produced in a body at rest, by the real motion of the spectator.

Let us suppose a man in a ship, to be carried along by a brisk gale, in a direction parallel to a shore, at no great distance from him ; while he keeps his eye upon the deck, the mast, the sails, or any thing about him in the ship ; that is to say, while he sees nothing but some part of the vessel

on board of which he is, and consequently every part of which moves with him, he will not perceive that the ship moves at all. Let him, after this, look to the shore, and he will see the houses, trees, and hills, run from him in a direction contrary to the motion of the vessel; and supposing him to have received no previous information on this subject, he might naturally conclude, that the apparent motion of these bodies was real.

In a similar situation to this, we may conceive the inhabitants of the earth; who, in early times, knowing nothing of the true structure or laws of the universe, saw the sun, the stars, and the planets, rise and set, and perform an apparent revolution about the earth. They had no idea of the motion of the earth, and therefore all this appearance seemed reality. But as it is highly reasonable to suppose, that as soon as the slightest hint should be given to the man, of the motion of the vessel, he would begin to form a new opinion, and conceive it to be more rational, that so small a thing as the ship should move, rather than all that part of the earth which was open to his view; so, in the same manner, no sooner was an idea formed, of the vast extent and greatness of the universe, with respect to this earth, than mankind began to conceive it would
be

be more rational that the earth should move, than the whole fabric of the heavens.

By another familiar instance, it will be easy to shew the young pupil, that as the eye does not perceive it's own motion, it always judges from appearances. Let a person go into a common windmill, and desire the miller to turn the mill round while he is sitting within it, and his eyes fixed on the upright post in the center thereof; this post, though at rest, will appear to him to turn round with considerable velocity, the real motion of the mill being the cause of the apparent motion of the swivel post. Having thus obviated the objections which arise from the testimony of the senses, we may now proceed to consider the arguments which tend more directly to prove the motion of the earth.

All the celestial motions will, on this supposition, be incomparably more simple and moderate.

This opinion is much more agreeable to our notions of final causes, and our knowledge of the œconomy of nature; for if the earth be at rest, and the stars, &c. move round it once in 24 hours, their velocity must be immense; and it is

certainly more agreeable to reason, that one single body, and that one of the smallest, should revolve on it's own axis in 24 hours, than that the whole universe should be carried round it, in the same time; with inconceivable velocity.

The rotation of the earth round it's axis is analogous to what is observed in the sun, and most of the planets; it being highly probable, that the earth, which is itself one of the planets, should have the same motion as they have, for producing the same effect: and it would be as absurd in us to contend for the motion of the whole heavens round us in 24 hours, rather than allow a diurnal motion to our globe, as it would be for the inhabitants of Jupiter to insist that our globe, and the whole heavens, must revolve round them in ten hours, that all it's parts might successively enjoy the light, rather than grant a diurnal motion to their habitation.

All the phænomena relative to this subject, are as easily solved on the supposition of the earth's motion, as on the contrary hypothesis. The truth of this position is pleasingly illustrated by the armillary sphere, which is shewn, fig. 2, pl. XIII. The exterior circles represent the sphere of the heavens; within these, and in the center of the sphere,

ſphere, is placed a little globe, ſupported by a ſteel axis. *a* and *b* are two milled nuts. By moving the nut *a*, the ſmall globe may be turned round the ſame way we ſuppoſe our earth to revolve, while the outer part, or ſphere, remains fixed; but if the nut *b* be turned the contrary way, the ſphere will move round the globe, the ſame way as the heavens appear to move.

Thus by this machine, the real motion of the earth round it's axis, within the ſphere of the heavens, or the apparent motion of the heavens round the earth, may be repreſented: and it will ſhew, that the reſult of the various problems are the ſame, whether we ſuppoſe the heavens to move round the earth, or the earth to revolve on it's axis.

Befides the foregoing conſiderations, there are ſeveral arguments to be deduced from the higher parts of aſtronomy, which demonſtrably prove the diurnal motion of the earth.

DEFINITIONS.

Before we enter into a further explanation of phænomena, it will be neceſſary to define ſome of the principal circles of the globe. The reader
will

will comprehend more fully these definitions, and attain more accurate ideas of these circles, by placing, while he is reading them, a terrestrial globe, or armillary sphere, before him.

It may, however, be necessary to premise, that we are at liberty to suppose as many circles as we please, to be described on the earth; and the plane of any of these to be continued from the earth, until it marks a corresponding circle in the concave sphere of the heavens.

Among these circles, the HORIZON is the most frequently named. Properly speaking, there are two circles called by this name, but distinguished from each other by added epithets, the one being called the SENSIBLE, the other the RATIONAL HORIZON.

In general terms, the HORIZON may be defined to be an imaginary circle, that separates the visible from the invisible part of the heavens.

If a spectator supposes the floor or plane on which he stands, to be extended every way, till it reach the starry heavens, this plane is his SENSIBLE HORIZON.

The RATIONAL HORIZON is a circle, whose plane is parallel to the former, but passing through the center of the earth.

The rational horizon divides the concave sphere of the heavens into equal parts, or hemispheres; the objects that are in the upper hemisphere will be visible; such as are in the lower hemisphere will be invisible to the spectator.

Though the globe of the earth appears so large to those who inhabit it, yet it is so minute a speck, when compared to the immense sphere of the heavens, that at that distance the planes of the rational and sensible horizons coincide; or in other words, the distance between them in the sphere of the heavens, is too small for admeasurement.

To illustrate this, let $A B C D$, fig. 1, plate III. represent the earth; $z h n o$ the sphere of the starry heaven. If an inhabitant of the earth stands upon the point A , his sensible horizon is $f e$, his rational one $h o$; the distance between the planes of these two horizons is $A F$, the semidiameter of the earth, which is measured in a great circle upon the sphere of the heaven, by the angle $e F o$, or the arc $e o$; this arch is so small

small a circle, as $z h n o$ would amount to several degrees, and consequently the difference between the sensible and the rational horizon, would be great enough to be measured by observation. If we represent the sphere of the heaven by a larger circle, the semidiameter of the earth $A F$ measured in this circle, will amount to fewer degrees; for the arc $E O$ is less than the arc $e o$; and the larger the sphere of the heaven is, in proportion to the globe of the earth, the less sensible is the difference between the two horizons. Now as the sphere of the earth is but as a point, when compared to the starry heaven, the difference between the sensible and rational horizon will be insensible.

From what has been said, it appears that the only distinction between the sensible and rational horizon, arises from the distance of the object we are looking at.

The sensible horizon is an imaginary circle, which terminates our view, when the objects we are looking at are upon the earth's surface. The rational horizon is an imaginary circle, which terminates our view, when the objects we are looking at are as remote as the heavenly bodies.

As

As the rational horizon divides the apparent celestial sphere into two equal hemispheres, and serves as a boundary, from which to measure the elevation or depression of celestial objects; those in the upper, or visible hemisphere, are said to be high, or elevated, above the horizon; and those in the other hemisphere are called low, or below the horizon.

The earth being a spherical body, the horizon, or limits of our view, must change as we change our place; and therefore, every place upon the earth has a different horizon. Thus if a man lives at A, fig. 2, plate III. his horizon is G e: if he lives at b, his horizon is H D: if at c, it is A E. From hence we obtain another proof of the sphericity of the earth; for if it were flat, all the inhabitants thereof would have the same horizon.

The point in the heavens, which is directly over the head of a spectator, is called the ZENITH.

That point which is directly under his feet, is called the NADIR.

If a man lives at A, fig. 2, plate III. his zenith is A, his nadir E. If he lives at b, his
zenith

zenith is B, his nadir F ; consequently the zenith and horizon of an observer remains fixed in the heavens, so long as he continues in the same place ; but he no sooner changes his position, than the horizon touches the earth in another point, and his zenith answers to a different point in the heavens.

The **AXIS** of the earth is an imaginary line, conceived to be drawn through the center of the earth, upon which line it's revolutions are made.

The **POLES** of the earth are the extremities of it's axis, or those two points on it's surface, where it's axes terminate ; one of these is called the **NORTH**, and the other the **SOUTH POLE**.

The poles of the heavens, or of the world, are those two points in the heavens, where the axis of the earth, if produced, would terminate ; so that the north pole of the heavens is exactly over the north pole of the earth, and the south pole of the heavens is directly over the south pole of the earth.

The **EQUATOR** is an imaginary circle, which is supposed to be drawn round the earth's surface, in the middle between the two poles. It divides the earth into two equal parts, one of which is called

the NORTHERN, the other the SOUTHERN HEMI-
SPHERE.

If we suppose the plane of the earth's equator to be extended all ways, as far as the heavens, it will mark there a circle, that will divide the heavens into two equal parts; this circle is called sometimes the EQUINOCTIAL, sometimes the CELESTIAL EQUATOR.

The meridian of any place is a circle supposed to pass through that place, and the poles of the earth; we may therefore imagine as many meridians as there are places upon the earth, because any place that is ever so little to the east or west of another place, has a different meridian.

By the foregoing definition, we see that the meridian of any place is immoveably fixed to that place, and carried round along with it by the rotation of the earth. The meridian marks upon the plane of the horizon the north and south points.

The circle which the sun appears to describe every year, in the concave sphere of the heavens, is called the ECLIPTIC. It is thus denominated, because in all eclipses the moon is either in or
near

near the plane of it. But as the earth moves round the sun, in the plane of the ecliptic, it is likewise the plane of the earth's orbit.

If we conceive a zone, or belt, about sixteen degrees broad in the concave sphere of the heaven, with the ecliptic passing through the middle of it, this zone is called the ZODIAC.

The stars in the zodiac are divided into TWELVE SIGNS, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces.

We may imagine as many circles as we please drawn on the globe, parallel to the equator, and these will decrease in their diameter, as they approach nearer the poles.

The TROPICS are two lesser circles of this kind, parallel to the equator, and $23\frac{1}{2}$ degrees distant from it; one in the northern hemisphere, which is called the TROPIC OF CANCER; the other in the southern, which is called the TROPIC OF CAPRICORN. If we conceive the planes of these circles expanded, till they reach the starry heaven, the sun will be seen to move in that circle which corresponds to the tropic of cancer on the longest summer's

summer's day, and in that circle which answers to the tropic of capricorn on the shortest winter's day.

The polar circles are two lesser circles, conceived to be described at $23\frac{1}{2}$ degrees distance from each pole.

The axis of the earth is inclined to the plane of the ecliptic, and makes with it an angle of $66\frac{1}{2}$ degrees ; therefore the plane of the earth's equator cannot coincide with the plane of the ecliptic, but these two planes make with one another an angle of $23\frac{1}{2}$ degrees.

OF THE ANNUAL MOTION OF THE EARTH.

The foregoing definitions being understood, we may now proceed in the description of the phænomena of our system. It is owing to the industry of modern astronomers, that the annual motion of the earth has been fully evinced ; for though it's motion had been known to, and adopted by many among the ancient philosophers, yet they were not able to give their opinions that degree of probability, which is attainable from modern discoveries, much less the evidence arising from those demonstrative

proofs of which we are now in possession. We shall, therefore, enumerate some of the reasons which induce astronomers to believe that the earth moves round the sun.

The celestial motions become incomparably more simple, and free from those looped contortions which must be supposed in the other case, and which are not only extremely improbable, but incompatible with what we know of motion.

This opinion is also more reasonable, on account of the extreme minuteness of the earth, when compared with the immense bulk of the sun, Jupiter, and Saturn; and there are no known laws of motion, according to which so great a body as the sun can revolve about so small a one as the earth.

The sun is the fountain of light and heat, which it darts through the whole system; it ought, therefore, to be in the center, that its influence may be regularly diffused through the whole heavens, and communicated in just gradations to the whole system.

When we consider the sun as the center of the system, we find all the bodies moving round it, agreeable

agreeable to the universal laws of gravity; but upon any other consideration we are left in the dark.

The motion of the earth round the sun, accords with that general harmony, and universal law, which all the other moving bodies in the system observe, namely, that the squares of the periodic times are as the cubes of the distances; but if the sun moves round the earth, that law is destroyed, and the general order of symmetry in nature interrupted.

It is incontestibly proved, by observation, a motion having been discovered in all the fixed stars, which arises from a combination of the motion of light with the motion of the earth in its orbit.

It will be clearly shewn in its place, that Venus and Mercury move round the sun in orbits that are between it and the earth; that the orbit of the earth is situated between that of Venus and Mars; and that the orbits of Mars, Jupiter, &c. are exterior to, and include the other three.

OF THE APPARENT MOTION OF THE SUN,
ARISING FROM THE EARTH'S ANNUAL MOTION
ROUND IT.

As when a person sails along the sea coast, the shore, the villages, and other remarkable places on land, appear to change their situation, and to pass by him; so it is in the heavens. To a spectator upon the earth, as it moves along it's orbit, or sails as it were through celestial space, the sun, the planets, and the fixed stars, appear to change their places.

The apparent change of place is of two sorts; the one is that of bodies at rest, the change of whose place depends solely on that of the spectator; the other is that of bodies in motion, whose apparent change of place depends as well on their own motion, as on that of the spectator. We shall here consider only that apparent change which takes place in those which are at rest, and which is owing wholly to the motion of the earth.

To shew that the sun, when seen from the earth, will appear to move in the same manner, whether the sun revolves round the earth, or whether the earth revolves round the sun: First, let us suppose the earth at rest, without any motion

tion of it's own, and let the sun be supposed to revolve round it in the orbit A B C D, fig. 1, plate IV. and let E F G H be a circle in the concave sphere of the starry heavens ; as the sun moves in the order of the letters A B C D in it's orbit, it will appear to a spectator on the earth to have described the circle E F G H. When the sun is at A, it will appear as if it was among the fixed stars that are at E ; when it is at B, it will appear among the fixed stars at F ; when at C, among those at H ; and when it is at D, it will appear among the fixed stars at G. Indeed, the fixed stars and the sun are not seen at the same time ; but we have shewn, that we may tell in what part of the heavens the sun is, or what fixed stars it is near, by knowing those which are opposite to it, or come to the south at midnight. Therefore, if we find that any set of stars, as those at G for instance, come to the south at midnight, we may be sure that they are opposite to the sun ; and consequently, if we could see the stars in that part of the heaven where the sun is, we should find them to be those at F.

Secondly, let us suppose that S is the sun, that it has no motion of it's own, that it rests within the orbit A B C D, in which we shall now suppose the earth to move, in the order of the letters

A B C D. Upon this supposition, when the earth is at A, the sun will appear in that part of the heavens where the stars H are; when the earth is at B, the sun will appear in that part of the heavens where the stars G are; when the earth is at C, the sun will appear in that part of the heavens where the stars E are; and as the earth revolves round the sun, in the orbit A B C D, the sun will appear to a spectator on the earth to describe the circle G H E F.

Thus whether the earth is at rest, and the sun revolves in the orbit A B C D; or the sun is at rest, and the earth revolves in the same orbit, a spectator on the earth will see the sun describe the same circle E F G H, in the concave sphere of the heavens.

Hence if the plane of the earth's orbit be imagined to be extended to the heavens, it would cut the starry firmament in that very circle, in which a spectator in the sun would see the earth revolve every year: while an inhabitant of the earth would observe the sun to go through the same circle, in the same space of time that the solar spectator would see the earth describe it.

The inhabitants of all the other planets will observe just such motions in the sun as we do, and for the very same reasons; and the sun will be seen from every planet to describe the same circle, and in the same space of time, that a spectator in the sun would observe the planet to do. For example, an inhabitant of Jupiter would think that the sun revolved round him, describing a circle in the heavens in the space of twelve years: this circle would not be the same with our ecliptic, nor would the sun appear to pass through the same stars which he does to us. On the same account, the sun, seen from Saturn, will appear to move in another circle, distinct from either of the former; and will not seem to finish his period in less time than thirty years. Now as it is impossible that the sun can have all these motions really in itself, we may safely affirm, that none of them are real, but that they are all apparent, and arise from the motions of the respective planets.

One phænomenon arising from the annual motion of the earth, which has already been slightly touched upon, may now be more fully explained; for as from this motion, the sun appears to move from west to east in the heavens, if a star rises or sets along with the sun at any time, it will in the

course of a few days rise or set before it, because the sun's apparent place in the heavens will be removed to the eastward of that star. Hence those stars which at one time of the year set with the sun, and therefore do not appear at all, shall at another time of the year rise when the sun sets, and shine all the night. And as any one star shifts it's place with respect to the sun, and in consequence of that with respect to the hour of the night, so do all the rest. Hence it is that all those stars, which at one time of the year appear on any one side of the pole star in the evening, shall in half a year appear on the contrary side thereof.

OF PHÆNOMENA OCCASIONED BY THE ANNUAL
AND DIURNAL MOTIONS OF THE EARTH.

First, of those that arise from the diurnal motion. As the earth is of a spherical figure, that part of it which comes at any time under the confined view of an observer, will seem to be extended like a plane; and the heavens will appear as a concave spherical superficies, divided by the aforesaid plane into two equal parts, one of which is visible, the other concealed from us by the opacity of the earth.

Now

Now the earth, by it's revolution round it's axis, carries the spectator and the aforefaid plane from WEST TO EAST; therefore all those bodies to the east, which could not be seen because they were below the plane of the horizon, will become visible, or rise above it, when, by the rotation of the earth, the horizon sinks as it were below them. On the other hand, the opposite part of the plane, towards the west, rising above the stars on that side, will hide them from the spectator, and they will appear to set, or go below the horizon.

As the earth, together with the horizon of the spectator, continues moving to the east, and about the same axis, all such bodies as are separated from the earth, and which do not partake of that motion, will seem to move uniformly in the same time, but in an opposite direction, that is, from EAST TO WEST; excepting the celestial poles, which will appear to be at rest. Therefore, when we say, that the whole concave sphere of the heavens appears to turn round upon the axis of the world, whilst the earth is performing one rotation round it's own axis, we must be understood to except the two poles of the world, for these do not partake of this apparent motion.

It is, therefore, on account of the revolution of the earth round it's axis, that the spectator imagines the whole starry firmament, and every point of the heaven, (excepting the two celestial poles) to revolve about the earth from east to west every twenty-four hours, each point describing a greater or lesser circle, as it is more or less remote from one of the celestial poles.

Although every place on the surface of the terraqueous globe, is illuminated by all the stars which are above the horizon of that place; yet when the sun is above the horizon, his light is so strong, that it quite extinguishes the faint light of the stars, and produces DAY. When the sun goes below the horizon, or more properly, when our horizon gets above the sun, the stars give their light, and we are in that state which is called NIGHT.

Now as the earth is an opaque spherical body, at a great distance from the sun, ONE HALF of it will always be illuminated thereby, while the other half will remain in darkness.

The circle which distinguishes the illuminated face of the earth from the dark side, and is the boundary between light and darkness, is generally

rally called THE TERMINATOR. A line drawn from the center of the sun to the center of the earth, is perpendicular to the plane of this circle.

When any point in the globe first gets into the enlightened hemisphere, the sun is just risen to that part; when it gets half-way, or to it's greatest distance from the terminator, it is then NOON; and when it leaves the enlightened hemisphere, it is then SUN-SET; but it still enjoys some light from the sun, which is reflected by the atmosphere, till it gets eighteen degrees beyond the terminator; this glimmering light is called TWILIGHT.

We have already shewn, that the daily motion of the sun from east to west, is not a real, but an apparent one, which is owing to the rotation of the earth round it's axis. Now if the sun had no other motion but this apparent one, it would seem to go once round the earth, in the time of one complete rotation, or in 23 hours, 56 minutes; which is the case with any of the fixed stars, and is therefore the length of a SIDERIAL DAY.

But the sun is found to take up a longer time to complete it's apparent revolution; for if it is
in

in the south of any particular place at twelve o'clock at noon to-day, it will not complete an apparent revolution, so as to return to the south of that place again, till twelve o'clock at noon on the next day, and consequently the time of this apparent revolution is twenty-four hours.

This difference is owing to another apparent motion of the sun, which is called his annual or yearly motion. For the sun does not continue always in the same place in the heaven, as the fixed stars do; but if it is seen at M, fig. 2, pl. IV. one day, near the fixed star R, it will have shifted it's place the next day, and will be near to some other fixed star L. This motion of the sun is from west to east, and one entire revolution is completed in a year.

Suppose, therefore, that the sun, when it is at M, near to the fixed star R, appears in the south of any particular place S; and then imagine the earth to turn once round upon it's axis from west to east, or in the direction S T V W, so that the place may be returned to the same situation; after this rotation is completed, the star R will be in the south of the place as before; but the sun having, in the mean time, moved eastwards, and being near to the star L, or to the east of R, will

will not be in the south of the place S, but to the eastward of it: upon this account, the place S must move on a little farther, and must come to T before it will be even with the sun again, or before the sun will appear exactly in the south.

This may be illustrated by an instance. The two hands of a watch are close together, or even with one another at twelve; they both turn round the same way, but the minute hand turns round in a shorter time than the hour hand; when the minute hand has completed one rotation, and is come round to twelve, the hour hand will be before it, or will be at one; so that the minute hand must move more than once round, in order to overtake the hour hand, and be even with it again.

As this subject is of some importance, we shall endeavour to render it more clear, by placing it in a different point of view: the more so, as it may accustom the young pupil to reason on both hypotheses, namely, the motion of the sun, and that of the earth.

The diameter of the earth's orbit is but a physical point, in proportion to the distance of the stars; for which reason, and the earth's uniform motion

motion on it's axis, any given meridian will revolve from any star to the same star again, in every absolute turn of the earth upon it's axis, without the least perceptible difference of time being shewn by a clock which goes exactly true.

If the earth had only a diurnal, without an annual motion, any given meridian would revolve from the sun to the sun again, in the same quantity of time as from any star to the same star again; because the sun would never change his place, with respect to the stars. But as the earth advances almost a degree eastward in it's orbit, in the time that it turns eastward round it's axis; whatever star passes over the meridian on any day with the sun, will pass over the same meridian on the next day, when the sun is almost a degree short of it, that is, 3 min. 56 seconds sooner. If the year contained only 360 days, the sun's apparent place, so far as his motion is equable, would change a degree every day, and then the siderial days would be just four minutes shorter than the solar.

Let A B C D E F G H, fig. 3, plate IV. be the earth's orbit, in which it goes round the sun every year, according to the order of the letters; that is, from west to east, and turns round it's
axis

axis the same way, from the sun to the sun again in every twenty-four hours. Let S be the sun, and R a fixed star, at such an immense distance, that the diameter of the earth's orbit bears no sensible proportion to that distance; Nmn the earth in different points of it's orbit. Let Nm be any particular meridian of the earth, and N a given point, or place, lying under that meridian.

When the earth is at A , the sun S hides the star R , which would always be hid if the earth never moved from A , and consequently as the earth turns round it's axis, the point N would always come round to the sun and the star at the same time.

But when the earth has advanced through an eighth part of it's orbit, or from A to B , it's motion round it's axis will bring the point N an eighth part of a day, or three hours, sooner to the star than to the sun. For the star will come to the meridian in the same time as though the earth had continued in it's former situation at A , but the point N must revolve from N to n , before it can have the sun upon it's meridian. The arc Nn being therefore the same part of a whole circle, as the arc AB , it is plain that any star which comes to the meridian at noon, with the sun, when

when the earth is at A, will come to it at nine o'clock in the forenoon, when the earth is at B.

When the earth has passed from A to C, one-fourth part of it's orbit, the point N will have the star upon it's meridian, or at six in the morning, six hours sooner than it comes round to the sun; but the point N must revolve six hours more, before it has mid-day by the sun: for now the angle ASD is a right angle, and so is NDn; that is, the earth has advanced 90 degrees on it's axis, to carry the point N from the star to the sun; for the star always comes to the meridian when Nm is parallel to RSA; because DS is but a point in respect to RS. When the earth is at D, the star comes to the meridian at three in the morning, at E, the earth having gone half round it's orbit; N points to the star at midnight, it being then directly opposite to the sun; and, therefore, by the earth's diurnal motion, the star comes to the meridian twelve hours before the sun, and then goes on, till at A it comes to the meridian with the sun again.

Thus it is plain, that one absolute revolution of the earth on it's axis, (which is always completed when any particular star comes to be parallel

parallel to it's situation at any time of the day before) never brings the same meridian round from the sun, to the sun again ; but that the earth requires as much more than one turn on it's axis, to finish a natural day, as it has gone forward in that time, which, at a mean state, is a 365th part of a circle.

From hence we obtain a method of knowing by the stars, whether a clock goes true or not. For if through a small hole in a window-shutter, or in a thin plate of metal fixed to a window, we observe at what time any star disappears behind a chimney, or corner of a house, at a little distance ; and if the same star disappears the next night, 3 min. 56 seconds, sooner by the clock ; and on the second, 7 minutes, 52 seconds sooner ; the third night, 11 minutes, 48 seconds sooner, and so on every night ; it is an infallible sign that the machine goes true ; otherwise it does not, and must be regulated accordingly. This method may be depended on to nearly half a second.

OF THE SEASONS OF THE YEAR.

It is our business under the present head to account for the phænomena of the seasons, those grateful vicissitudes on which so much, both of

the business and happiness of man depends. As the seasons are applied in the hieroglyphic language of the bible, to mark the different stages of man's progress in virtue, the rise, meridian glory, decline, and consummation of the church, or the different dispensations of divine goodness and truth to man; we do not think the reader will be offended, if we present him with a few observations on this head, extracted from the works of an elegant moralist.

The natural advantages which arise from the position of the earth which we inhabit, with respect to the other planets, afford much employment to mathematical speculation; by which it has been discovered, that no other conformation of the system could have given such commodious distributions of light and heat, or imparted fertility and pleasure to so great a part of a revolving sphere.

The moralist may with equal reason observe, that our globe seems equally fitted for the residence of a being, placed here only for a short time, whose task is to advance himself to a higher and happier state of existence, by unremitting vigilance of caution, and activity of virtue. The duties of man are such as human nature does not willingly

willingly perform, and such as those are inclined to delay, who intend some time to fulfil them. It was, therefore, necessary, that this universal reluctance should be counteracted, and the drowsiness of hesitation awakened into resolve; that the danger of procrastination should be always in view, and the fallacies of security be hourly detected. To this end, all the appearances of nature uniformly conspire: whatever we see on every side, reminds us of the lapse of time, and the flux of life. The day and night succeed each other; the rotation of the seasons diversifies the year; the sun attains the meridian, declines and sets; and the moon every night changes its form.

The day may be considered as an image of the year, and a year as the representation of life. The morning answers to the spring, and the spring to childhood and youth. The noon corresponds to the summer, and the summer to the strength of manhood. The evening is an emblem of autumn, and autumn of declining life. The night, with its silence and darkness, shews the winter, in which all the powers of vegetation are benumbed; and the winter points out the time when life shall cease, with its hopes and pleasures.

He that is carried forward, however swiftly, by a motion equable and easy, perceives not the change of place, but by the variation of objects. If the wheel of life, which rolls thus silently along, passed on through undistinguishable uniformity, we should never mark it's approaches to the end of the course. If one hour were like another; if the passage of the sun did not shew it's wasting; if the change of seasons did not impress upon us the flight of the year; quantities of duration, equal to days and years, would glide away unobserved. If the parts of time were not variously coloured, we should never discern their departure or succession; but should live thoughtless of the past, and careless of the future, without will, and perhaps without power, to compare the time which is already lost, with that which may probably remain.

But the course of time is so visibly marked, that it is even observed by nations, who have raised their minds very little above animal instinct. That these admonitions of nature may have their due effect; let him that desires to see others happy, make haste to give while his gift can be enjoyed; and remember, that every moment of delay takes away something from the value of his benefaction. And let him who pro-
poses

poses his own happiness, reflect, that while he forms his purpose, the day rolls on, and the night cometh, when no man can work.

In order to explain the causes of those changes that are termed the seasons of the year, it will be necessary to premise a few considerations: First, that on account of the immense distance of the sun from the earth, the rays which proceed from it may be considered as parallel to each other. Secondly, that only one-half of a globe can be illuminated by parallel rays, and therefore only one-half of the earth will be enlightened by the sun at one time. Thirdly, that we may call the line which divides light from darkness, the terminator.

These considerations, as well as some of the following deductions, will be rendered more clear, by a survey of fig. 1, 2, and 3, pl. VI. where $N \text{ } \text{Æ} \text{ } S \text{ } Q$ represents the globe of the earth; N 80 S, N 70 S, &c. different meridians intersecting the equator $\text{Æ} \text{ } Q$ at right angles, and passing through the poles N and S ; $T \text{ } T$ the terminator; B a brass ball, to represent the sun, with parallel rays proceeding from it.

In fig. 3, the poles coincide with the terminator.

In fig. 1, the north pole is altogether in the illuminated hemisphere, and the south pole in the dark hemisphere.

In fig. 2, the southern pole is in the enlightened part, and the north pole in the dark hemisphere.

It is day in any given place on the globe, so long as that place continues in the enlightened hemisphere; and when, by the diurnal rotation of the earth on it's axis, it is carried into the dark hemisphere, it becomes night to that place.

The length of the day and the night depend on the position of the terminator, with respect to the axis of the earth.

If the poles be situated in the terminator, as in fig. 3, every parallel will be divided into two equal parts; and as the uniform motion of the earth causes any given place to describe equal parts of it's parallel in equal times, the day and the night would be equal on every parallel of latitude;

latitude ; that is, all over the globe, except at the poles, where the sun would neither rise nor set, but continue in the horizon.

But if, as in fig. 1 and 2, the axis be not placed in the plane of the terminator, the terminator will divide the equator into two equal parts, but the parallels into unequal parts ; those which are situated towards the enlightened pole, will have a greater part of their circumference in the enlightened, than in the dark hemisphere ; while similar parallels toward the other pole will have the greater part of their circumference in the dark hemisphere. Whence it follows, that the first-mentioned parallels will enjoy longer days than nights ; and the contrary will happen to the latter, where the day will be the shortest, and the night the longest. All this is evident from the bare inspection of the figures ; it is also observable, that the disproportion is greatest in the greatest latitude ; and that those places, whose distance from the pole is less than that of the pole from the terminator, must enjoy either a constant day, or a constant night ; because they are never carried into the opposite hemisphere by the diurnal rotation of the earth. In this position of the axis, the inhabitants on one side of the equator may be said to enjoy summer, and those

on the other side winter with respect to each other.

From what has been said, it is plain that the vicissitudes in the days and nights are occasioned by the position of the terminator, or boundary of light and darkness, with the axis of the earth, or in other words, of the different aspect of the earth with respect to the sun.

We have now only to shew what causes the change of position in the terminator, which is,

1. The inclination of the earth's axis to the plane of the ecliptic, or orbit in which it moves.
2. That through the whole of it's annual course the axis of the earth preserves it's position, or continues parallel to itself; that is, if a line be conceived as drawn parallel to the axis while the earth is in any one point of it's orbit, the axis will in every other position of the earth be parallel to the said line.

If the axis of the earth were perpendicular to the place of it's orbit, the equator and the orbit (or ecliptic) would coincide; and as the sun is always in the plane of the ecliptic, it would in this case be always over the equator, as in fig. 3, and the two poles would be in the terminator,
and

and there would be no diversity in the days and nights, and but one season of the year; but as this is not the case, we may fairly infer that the axis of the earth is not perpendicular to the plane of it's orbit.

But if the earth's axis be inclined to the plane of the ecliptic when the earth is as at fig. 1, plate VI. the pole N will be towards the sun, and the pole S will be turned from it; but just the contrary will happen, when the earth by going half round the sun has arrived at the opposite point in it's orbit: by this means the sun will not be always in the equator, but at one time of the year it will appear nearer to one of the poles, and at the opposite time it will appear nearer to the other. To this the change of seasons is owing; for when the sun leaves the equator and approaches to one of the poles, it will be summer on that side of the equator, and when the sun departs from thence and approaches to the other pole, then it will be winter. From the inclination of the axis, each part of the earth enjoys the benefit of summer in it's turn: for it is evident, from what has been said already, that when it is winter towards one of the poles, on one side the equator, it is summer towards the other pole, or on the other side of the equator.

To

To elucidate still further the changes in the seasons, we shall beg the reader's attention to the figures in plates V. and VI. which represent one of the most simple instruments hitherto contrived for explaining them. Fig. 1, plate V. is the whole of the instrument. Fig. 1, 2, and 3, plate VI. two portions of it thus exhibited, in order to give a more distinct view of the phenomena.

If we now suppose the earth to be at Libra, as in fig. 1, plate V. then will the sun appear to be at the opposite point of the ecliptic in Aries, the time of our vernal equinox. The terminator will pass through the poles of the world, and divide every parallel to the equator into two equal parts; consequently the nocturnal and diurnal arches, or the length of the day and night, will be equal in all places over the world. See fig. 3, plate VI.

But if you conceive the earth by it's annual motion to have moved to Capricorn, the axis keeping parallel to itself; the north pole will by this motion have gradually advanced into the enlightened hemisphere, so that the whole northern polar circle will, when it has arrived, be in the illuminated hemisphere, while the southern pole

pole recedes into darknefs, and all the northern parts will enjoy long days and fummer, while the fouthern parts will have fhort days and winter.

Again, while the earth is defcribing the next quarter of it's orbit, or going from Capricorn through Aquarius and Pifces to Aries, the north pole approaches the terminator in the fame proportion that it before receded from it, and confequently the diurnal arches gradually leffen till it arrives at Aries, when the poles will again coincide with the terminator, and thus caufe the days and nights to be every where equal. This is called the AUTUMNAL EQUINOX.

During the next quarter, or while the earth is going through Taurus and Gemini, the north pole will gradually recede from the light, while the fouthern one advances into it; and the days will fhorten in the northern hemisphere, and lengthen in the fouthern, until the earth is arrived at Cancer, the fun then appearing in Capricorn, when the north pole will be juft as far within the dark as in June it was in the enlightened hemisphere. This time is called the WINTER SOLSTICE. The days every where in the northern hemisphere are now at the fhorteft, and to the fouthward they are at the longeft.

From

From the winter solstice to the vernal equinox the pole will approach the terminator, and the days will again lengthen in the northern hemisphere, and at the instant in which the axis again coincides with the plane, the natural year, consisting of 365 days, 5 hours, $48\frac{1}{2}$ minutes, is finished.

The pupil will observe, by considering the instrument, that during the whole revolution of the earth, one-half of the equator is always in the light, and the other half in darkness; and consequently, that under the equator the days and nights are always of an equal length.

While the earth is going from Libra to Aries, the north pole is constantly illuminated, and the south pole all the while in darkness; and for the other half of the year in a contrary state.

It is easy to perceive, by the foregoing explanation, that the inhabitants of the southern hemisphere have the same vicissitudes, though not at the same time, it being winter in one hemisphere while it is summer in the other.

There is still, however, one circumstance to be considered, namely, the daily apparent change
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in the sun's declination ; but this will be easily conceived, by attending to fig. 1, 2, and 3, pl. VI. and conceiving a line to be drawn from the center of the sun to the center of the earth, in each situation. This line may be called the central solar ray. About the 21st of December, when the earth is in Cancer, this ray will terminate or fall upon the southern tropic, or the tropic of Capricorn ; and consequently, by the earth's rotation round her axis, the inhabitants of every part of this circle will successively have the sun in their zenith ; or in other words, he will be vertical to them that day at noon, as the sun appears that day to be carried round in the tropic of Capricorn.

About the 19th of March, the earth is at Aries, and the sun will then appear in Libra ; the central solar ray terminates upon the surface of the earth, in the equator, as at fig. 3 ; and therefore the sun appears to be carried round in the celestial equator, and is successively vertical to those who live under that circle.

About the 21st of June, when the earth is in Capricorn, the central solar ray terminates on the surface of the earth, in the northern tropic, as at fig. 2 ; and for that day the sun appears to be carried round in the tropic of Cancer,
and

and is vertical to those who live under that circle. About the 22nd of September, the earth is in Libra, and the sun in Aries, and the central solar ray again terminates at the equator; consequently the sun again appears in the celestial equator, and is vertical to those who live under it.

We have seen, that as the sun moves in the ecliptic, from the vernal equinox to the tropic of Cancer, it gets to the north of the equator; or it's declination towards our pole increases. Therefore, from the vernal equinox, when the days and nights are equal, till the sun comes to the tropic of Cancer, our days lengthen, and our nights shorten; but when the sun comes to the tropic of Cancer, it is then in it's utmost northern limit, and returns in the ecliptic to the equator again. During this return of the sun, it's declination towards our pole decreases, and consequently the days decrease, and the nights increase, till the sun is arrived in the equator again, and is in the autumnal equinoctial point, when the days and nights will again be equal. As the sun moves from thence towards the tropic of Capricorn, it gets to the south of the equator; or it's declination towards the south pole increases. Therefore, at that time of year, our days shorten, and our nights lengthen, till the sun arrives at

the tropic of Capricorn; but when the sun is arrived there, it is then at it's utmost southern limit, and returns in the ecliptic to the equator again. During this return, it's distance from our pole lessens, and consequently the days will lengthen, as the nights will shorten, till they become equal, when the sun is come round to the vernal equinoctial point.

Our summer is nearly eight days longer than the winter. By summer is meant here the time that passes between the vernal and autumnal equinoxes; by winter, the time between the autumnal and vernal equinox. The ecliptic is divided into six northern, and six southern signs, and intersects the equator at the first of Aries, and the first of Libra. In our summer, the sun's apparent motion is through the six northern, and our winter through the six southern signs; yet the sun is 186 days, 11 hours, 51 minutes, in passing through the six first; and only 178 days, 17 hours, 58 minutes, in passing through the six last. Their difference, 7 days, 17 hours, 53 minutes, is the length of time by which our summer exceeds the winter.

In fig. 1, plate VII. A B C D represents the earth's orbit; S the sun in one of it's foci; when
the

the earth is at B, the sun appears at H, in the first point of Aries; and whilst the earth moves from B through C to D, the sun appears to run through the six northern signs, from γ through ϖ to \sphericalangle at F. When the earth is at D, the sun appears at F, in the first point of Libra; and as the earth moves from D through A to B, the sun appears to move through the six southern signs, from \sphericalangle through \wp to Aries at H.

Hence the line F H, drawn from the first point of Aries through the sun at S, to the first point of \sphericalangle , divides the ecliptic into two equal parts; but the same line divides the earth's elliptical orbit into two unequal parts. The greater part B C D is that which the earth describes in the summer, while the sun appears in the northern signs. The lesser part is D A B, which the earth describes in winter, while the sun appears in the southern signs. C the earth's aphelion, where it moves slowest, is in the greater part; A it's perihelion, is in the lesser part, where the sun moves fastest.

There are, therefore, two reasons why our summer is longer than our winter; first, because the sun continues in the northern signs, while the earth is describing the greater part of it's orbit;
and

and fecondly, becaufe the fun's apparent motion is flowier while it appears in the northern figns, than whilst it appears in the fouthern ones.

The fun's apparent diameter is greater in our winter than in fummer, becaufe the earth is nearer to the fun when at A in the winter, than it is when at C in the fummer. The fun's apparent diameter, in winter, is 32 min. 47 feconds; in fummer, 31 min. 40 feconds.

But if the earth is farther from the fun in fummer than in winter, it may be asked, why our winters are fo much colder than our fummers? To this it may be answered, that our fummer is hotter than the winter, firft, on account of the greater height to which the fun rifes above our horizon in the fummer; fecondly, the greater length of the days. The fun is much higher at noon in fummer than in winter, and confequently as it's rays in fummer are lefs oblique than in winter, more of them will fall upon the furface of the earth. In the fummer, the days are very long, and the nights very fhort; therefore the earth and air are heated by the fun in the day-time, more than they are cooled in the night; and upon this account, the heat will keep increafing in the fummer, and for the fame rea-

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son will decrease in winter, when the days shorten, and the nights lengthen.

ON SOME APPEARANCES WHICH DEPEND ON THE
CIRCLES OF THE HEAVENS, AND THE POSITION
OF THE OBSERVER IN RESPECT OF THEM.

For the more easy understanding of these phænomena, it will be necessary to premise two observations.

1. That the inclination of an axis, or orbit, is merely relative, because we compare it with some other axis, or orbit, which is not inclined at all. Thus our horizon being level to us, whatever place of the earth we are upon, we consider it as having no inclination; and yet, if we travel 90 degrees from that place, we shall then have an horizon perpendicular to the former, but it will still be level to us.

2. That half of the heavens are visible to an inhabitant, on any part of the earth.

OF A PARALLEL SPHERE.

An inhabitant of the earth, who lives at either of the poles, has one of the celestial poles in his zenith,

zenith, or directly over his head; the other in his nadir, or directly under his feet. The celestial equator will coincide with the horizon; and as the polar circles, the tropics, and all the circles of daily motion, are parallel to the equator, they will also be parallel to the horizon.

It is from this position of the circles of the sphere, in respect to the horizon of a person who lives at either pole, that he is said to live in a PARALLEL SPHERE.

As all the circles of daily motion are parallel to the equator, it follows, that all the heavenly bodies, to an inhabitant at the pole, are carried round by their apparent motion, in circles which are parallel to the horizon; (thus the sun, when above the horizon, appears to revolve in a circle parallel to it, and at an altitude equal to his distance from the equator) and consequently this motion can never make those rise, which move in the circles below the horizon, nor those set which move above it.

Hence, also, an inhabitant at the north pole has the sun above his horizon, and therefore perpetual day all the time the sun is on the north side of the equator, that is, for six months together.

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But

But the sun is below his horizon, and it is night with him all the time the sun is on the south side of the equator, which is also for six months ; or, in other words, the sun will be seen for half a year, and then it will be day ; and it will be hidden for half a year, and then it will be night.

OF A RIGHT SPHERE.

If an observer be situated under the equator, he will have the celestial poles in his horizon, and the celestial equator over his head, and at right angles with his horizon ; the other circles of daily motion being parallel to the equator, are also perpendicular, or at right angles with his horizon ; therefore, in a right sphere the rising and setting of the sun is in circles that make right angles with the horizon. It is from this position of these circles that he is said to live in a RIGHT SPHERE.

In a right sphere, the equator, and every parallel to it, is divided into two equal parts by the horizon, one half being above, the other half below it ; there is, therefore, a perpetual equinox under the equator, that is, the days and nights are equal to one another at all times of the year,

year, each day being 12 hours long, and every night of the same length.

OF AN OBLIQUE SPHERE.

In all other positions of the sphere, except those already described, the equator, and the circles parallel to it, are inclined to the horizon. In this case, the position of the sphere is said to be *OBLIQUE*. This position agrees with all those people who live neither under the pole, nor under the equator. One of the poles is elevated above the horizon, the other is depressed beneath it, and the equator is inclined to the horizon.

In plate XIV. fig. 1, the terrestrial globe is in the position of the oblique sphere.

It is evident, that in this situation all the parallels to the equator are divided by the horizon into two unequal parts, but the equator into two equal parts; consequently the day and night are never equal to an inhabitant in an oblique sphere, but when the sun is in the equator, that is, twice a year, on the 20th of March, and the 22d of September. All the rest of the year the days are either longer or shorter than the nights; for the sun, which always appears to move in

the ecliptic, describes one of the parallels to the equator, which are all cut by the horizon into two unequal parts. On the northern side of the equator, the days are longer than the nights, as long as the sun is on the north side of the equator; but the nights are longer than the days, when the sun is to the south of the equator.

The portion of the parallels above the horizon is greater in proportion as they are nearer the elevated pole; but when the distance of the parallel from the pole becomes less than the elevation of the pole, then that parallel, and all those which are included within it, are wholly above the horizon, no part of them ever setting or passing under it. The contrary happens in the parallels that are situated towards the depressed pole, a smaller portion of these being above the horizon, and the greater part lying under it. Those parallels which are nearer the depressed pole, than the elevation of the pole, or latitude of the place, remain perpetually (together with the stars included within them) under the horizon, and are never visible to us.

In an oblique sphere there is one parallel which is as far distant from the elevated pole, as the place is from the equator. This parallel is called
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the circle of PERPETUAL APPARITION, or the largest of all those which constantly appear; the stars included within it never either rise or set, though they are at times more elevated above the horizon than at others. Towards the other pole there is another circle, opposite to this, which is the circle of PERPETUAL OCCULTATION. All the stars that are contained within this, never rise, but lie hid under the horizon, and are never seen.

AN EXPLANATION OF THE PHÆNOMENA WHICH
ARISE FROM THE MOTION OF THE EARTH, AND
OF THE INFERIOR PLANETS, MERCURY AND
VENUS.

It will be necessary in this place to define more exactly some words which have been slightly explained before, and recall the reader's attention to some definitions that have been already given; and it is presumed, that these repetitions will not be an object of complaint, because they will answer the beneficial purpose of grounding the reader more firmly in the knowledge of the science, to which this essay is intended as an introduction.

When two planets are seen together in the same sign of the zodiac, and equally advanced therein, they are said to be in CONJUNCTION. But when they are in opposite signs of the zodiac, they are said to be in OPPOSITION. Thus a planet is said to be in opposition to the sun, when the earth is between the sun and the planet.

The elongation of a planet is it's apparent distance from the sun. When a planet is in conjunction with the sun, it has no elongation; when in opposition, it's elongation is 180 degrees.

THE NODES OF A PLANET'S ORBIT are those two points where the orbit cuts the plane of the ecliptic. We before observed, that the orbits of all the planets are inclined to the plane of the ecliptic, and consequently cross this plane. In fig. 3, plate III. A B C D is the plane of the ecliptic; E B F D is the orbit of a planet, in which the points B and D are the two nodes.

The LINE OF THE NODES is a line B D, supposed to be drawn through the sun from one node to the other. The LIMITS OF A PLANET'S ORBIT are two points in the middle between the two nodes. The point E is called the greatest northern limit, F the greatest southern limit.

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The greatest distance of the earth, or of any planet from the sun, is called it's *APHELION*, or higher apsis; it's least distance is called the *PERIHELION*, or lower apsis.

Thus in fig. 4, plate III. *A* is the place of the aphelion, *P* that of the perihelion.

The axis *P A*, fig. 4, of any planet's ellipsis, is called the *LINE OF THE APSIDES*; the extreme point of it's shortest diameter *T V* are the places of it's mean distance from the sun; and *S T*, or *S V*, the line of it's mean distance.

When a planet moves according to the order of the signs, it's motion is said to be *DIRECT*, or *IN CONSEQUENTIA*; but when it's motion is contrary to the order of the signs, it is said to be *RETROGRADE*, or *IN ANTECEDENTIA*.

The place in the starry heavens that any planet appears in, when seen from the center of the earth, is called it's *GEOCENTRIC PLACE*. The place where it would be seen in the celestial sphere, by an observer supposed to be in the sun, is called it's *HELIOCENTRIC PLACE*.

OF THE MOTIONS OF THE INFERIOR PLANETS,
VENUS AND MERCURY.

There are two different situations, in which an inferior planet will appear in conjunction with the sun; one when the planet is between the sun and the earth, the other when the sun is between the earth and the planet. Let A, fig. 2, plate VII. be the earth in it's orbit, E the place of Venus in her orbit E H G, S the sun, F V P Q R T D an arc in the starry heavens. In this situation the sun and Venus are on the same side of the earth, and will appear in the same point of the heavens, so as to be in conjunction. If the earth is at A, and Venus at G, they will also appear to be in conjunction.

If the earth is at A, the sun at S, the planet at E, nearer to the earth than the sun, it is called it's INFERIOR CONJUNCTION. But if the earth is at A, and the planet at G, farther from the earth than the sun, this is called the SUPERIOR CONJUNCTION of the planet.

If an inferior planet is at E, the earth at A, and the sun at S, the elongation is nothing, the planet being then in it's inferior conjunction. As the planet moves from E to y, it's elongation increases;

creases; for when it is at y , it appears in the line AyP , while the sun appears in the line ASQ ; so that PAQ will be it's elongation. When the planet is arrived at x , it appears in the line AxV , which is a tangent to it's orbit, and then it's elongation is VAQ , which is the greatest that can be on that side the sun; for after this, the elongation decreases. When the planet is at K , it's elongation is PAQ ; when at G , it is nothing, because it is then in it's superior conjunction; as the planet moves on from G , it's elongation again increases; for when it comes to C , it appears in the line ACR , and it's elongation is RAQ . When the planet comes to H , a line drawn from the earth through the planet is a tangent to the orbit, and the elongation is TAQ , the greatest it can have when it is on the other side of the sun; for after this, the elongation again decreases.

Hence it is clear, that the inferior planets can never appear far from the sun, but must always accompany it in it's apparent motion through the ecliptic. When we see either Venus or Mercury, it is either in an evening, in the west, soon after the sun has set; or in a morning, a little before the sun rises. Venus is indeed bright enough sometimes to be seen in the day-time, but then she is never

never far from the sun. The greatest elongation of Venus is about 48° , and of Mercury about 28° degrees.

From the apparent motions of the inferior planets, we derive an argument to prove the falsity of the Ptolemaic system. If the earth was within the orbit of Venus, as the Ptolemaic system supposes, she might be sometimes on one side of the earth, whilst the sun is on the opposite side; or Venus might be sometimes in opposition to the sun, but Venus is never seen in opposition. Therefore, the earth is on the outside of the orbit of Venus, and consequently the Ptolemaic system is not true. The same is also true of Mercury. But this, and some other circumstances relative to the motions of these planets, will be better understood by a planetarium than by any diagram.

If the earth is at A, fig. 2, plate VII. when Venus appears in any part of the arc E x G, she is westward from the sun, and therefore rises before him in the morning, and is called the MORNING STAR. When she appears any-where in the arc G H E, she is eastward from the sun, and therefore sets after him; is seen in the evening, and is then the EVENING STAR.

We have now to explain, why the inferior planets appear to move sometimes in one direction, sometimes in the contrary order, and at other times to be stationary. This is easily done on the Copernican system, it being the natural result of the respective situations and motions of the earth and these planets. But on the Ptolemaic system it is inexplicable, without calling in the aid of a very complicated hypothesis.

When the inferior planets are passing from their greatest elongation, on one side of the sun, through their superior conjunction, to their greatest elongation on the other side, their motion, as viewed from the earth, is direct. In order to explain this proposition, we shall first suppose the earth to be at rest at A, fig. 2, plate VII. and correct this supposition afterwards, by shewing that the apparent motion of Venus, or Mercury, seen from the earth, is the same in this respect, whether the earth moves in it's orbit, or rests at A.

The proposition to be explained is this : that as Venus, for instance, moves from x, it's greatest elongation on one side of the sun, through G it's superior conjunction, to H it's greatest elongation on the other side, it will appear

pear to a spectator upon the earth to move from west to east, according to the order of the signs; that is, it's geocentric motion will be direct.

The planets move round the sun from west to east, and consequently if there was a spectator at the sun, they would appear to him to move through the zodiac, according to the order of the signs; or in other words, the heliocentric motion of Venus is direct. Now if the sun, and the earth A, are both on the same side of the planet, a spectator at the earth is in the same situation with respect to the planet and it's motion, as if he had been at the sun: for whilst the planet is moving from x, through G to H, a spectator either at A or S is on the concave side of the planet's orbit; and consequently the planet will appear to move in the same manner from either; but the apparent motion of the planet, when seen from the sun, is direct, and consequently it's motion, when seen from the earth, will also be direct.

When Venus is at x, it appears to a spectator on the earth at A, to be in the line A x V, or is seen among the stars at V; when Venus has moved to K, it is seen among the fixed stars at P; when it has moved to G, it is in it's superior conjunction;

junction; when it has moved to C, it appears among the fixed stars at R; and when it is come to K, it appears among the fixed stars at T. Thus whilst Venus has moved in it's orbit from x, it's greatest elongation on one side of the sun, through G it's superior conjunction, to H it's greatest elongation on the other side, it appears to have described the arc V P Q R T in the concave sphere of the heavens; but the letters x K G C H lie from west to east, because they lie in the same direction that the planet moves round the sun; and the letters V P Q R T lie in the same direction with x K G C H. Therefore, as the planet seems to a spectator on the earth, to describe the arc V P Q R T, it's apparent motion, seen from the earth, is direct, or from west to east.

As the inferior planets move from their greatest elongation on one side of the sun, through their inferior conjunction, to their greatest elongation on the other side, their geocentric motion is RETROGRADE.

Whilst Venus, for instance, is moving from it's greatest elongation H, plate VII. fig. 3, through it's inferior conjunction E, to it's other greatest elongation x, it appears to a spectator

upon the earth at A, to move backwards, or from east to west, contrary to the order of the signs.

A spectator at the sun is on the concave side of the planet's orbit. But whilst Venus is moving from it's greatest elongation H on one side, through E it's inferior conjunction, to x it's greatest elongation on the other side, a spectator upon the earth is on the convex side of it's orbit.

Therefore, if a spectator at the sun S would see the planet move one way, a spectator at the earth A will see it move the contrary way; or the geocentric motion will be contrary to it's heliocentric motion, and therefore retrograde; for as seen from the sun, it's motion is always direct.

That two spectators, one at the earth, the other at the sun, as they are on contrary sides of the arc H E x, will see the planet apparently move contrary ways, may be rendered more plain by the following familiar consideration. If two men stand with their faces towards each other, and a ball is rolled along upon the ground, this ball will move from the right hand of one of the men towards his left, and from the left hand of the
the

the other towards his right. In like manner, if one man is at the earth A, and the other at the sun S, then whilst the planet is describing the arc H e x which is between them, it will appear to move from the right hand of the man at S towards his left, and from the left hand of the man at A towards his right.

Whilst the motion of Venus is direct, or while it is describing the arc x G H, it appears to move from V to T, among the fixed stars. But after it has been carried in it's orbit from H to Q, it appears in the line A z R, and is seen among the fixed stars at R. When it comes to E, it appears at Q; and when at y, it's apparent place in the heavens is at P. Thus as the planet passes from it's greatest elongation H on one side of the sun, through it's inferior conjunction E, to it's greatest elongation x on the other side, it apparently runs back from T to V.

Venus is stationary, or has no apparent motion for some time, when it is at it's greatest elongation; that is, when it is at H or x, and it's apparent place is either at T or V.

When either of the inferior planets, Venus for instance, is at it's greatest elongation H or x, a

line drawn from the earth through the planet, as AHT , or AXV , is a tangent to the orbit. Now though a right line touches a circle but in one point, yet some part of the circle greater than a point is so near to the tangent, as not to be distinguished from it. Thus the arc bd so nearly coincides with the tangent AHT , that a spectator's eye placed at A , could not distinguish the tangent from this part of the curve. Consequently, while the planet is describing this arc, no other change will be made in it's geocentric place, than if it was to move in the tangent.

But the geocentric place of the planet would not be altered, if the planet was to move in the tangent. For if it was to move from T towards A , or from A to V , the apparent place of it in the heavens would in one case be at T , in the other case at V . Therefore, while the planet is at it's greatest elongation, and is describing a small arc in it's orbit, that nearly coincides with the tangent, it's geocentric place does not alter, but it appears to continue for some time in the same part of the heavens, or is stationary.

We have hitherto supposed the earth to be at rest, and upon that supposition have explained the progress and regress, the conjunctions and
stations

stations of the inferior planets. If this supposition was true, $V T$, or the arc which the planet at any time describes in it's progress, and $T V$, the arc which it describes in it's regrefs, would always be in the same part of the heavens. The planet, when in conjunction, would always appear at Q among the same fixed stars ; and at it's elongation, or when it is stationary, it would always appear among the same fixed stars T on one side of the sun, and at V on the other side.

But this supposition is not true ; for the earth revolves in it's orbit $A B O$ round the sun. Now if the earth is at A , the time of either conjunction, the planet at this conjunction would appear among the fixed stars at Q , and the arcs of the greatest elongation $Q V$ and $Q T$, would be on each side of those stars. But if the earth is at B , at the time of either of the conjunctions, then at the time of this conjunction, the planet will appear in the line $B S T$, and be seen among the fixed stars at T , and the arcs of the greatest elongation will be on each side of these stars, that is, the conjunctions and elongations will happen in a different part of the heavens, when the earth is at B , from what they happen when the earth is at A ; in other respects, the foregoing phænomena will be much the same, notwithstanding the mo-

tion of the earth, only the planet will be more direct in the farthest part of the orbit, and less retrograde in the nearest.

The inferior planets always appear very near the sun; but by the motion of the earth in it's orbit, the sun appears in different parts of the heavens, in different times of the year. Therefore, the inferior planets, as they are always very near the sun, will also appear in different parts of the heavens, at different times of the year. And consequently, their conjunctions and greatest elongations will sometimes happen when they are in one part of the heavens, and sometimes when they are in another part. Venus seen from the earth, will appear to vibrate in an arc $V T$, half of which is on one side of the sun's apparent place, and half on the other side.

When an inferior planet, viewed from a superior, moves apparently retrograde, the superior planet has also an apparently retrograde motion.

When a superior planet, viewed from an inferior, appears stationary, the inferior planet viewed at the same time from the superior, is also stationary.

There

There is also another particular to be taken notice of, with regard to the apparent motion of the inferior planets, viz. that they do not seem to describe the ecliptic in the heavens as the sun does, but are observed to be sometimes above, and sometimes below it. The reason of this is, that their orbits are inclined to the plane of the earth's, having one-half above it, and the other below it, on which account they intersect the plane of the ecliptic, in a plane that passes through the center of the sun; this line is called the line of the nodes. These planets, therefore, never appear in the ecliptic, except when they are in their nodes; in all other parts of their orbit they seem to be more or less distant from it, according as they are situated with respect to them and the earth.

The distance of a planet from the ecliptic, as it would appear if seen from the center of the earth, is called it's GEOCENTRIC LATITUDE; as it would appear from the center of the sun, is called it's HELIOCENTRIC LATITUDE.

OF THE SUPERIOR PLANETS.

We have already observed, that the greatest elongation of either of the inferior planets is less

than 90 degrees, or a quarter of a circle ; so that they are never far from the sun, but constantly attend it. But the superior planets do not always accompany the sun, as we have shewn that the inferior ones do ; they are indeed sometimes in conjunction with it, but then they are also sometimes in opposition to, or 180 degrees from it.

Let S, fig. 3, plate VII. be the sun ; A B C D the orbit of any superior planet, Mars, for instance ; E F G the earth's orbit. If the earth be at E, the sun at S, and the planet at D, the sun and the planet will be both on the same side of the earth, and consequently the planet will appear in conjunction with the sun ; but as the orbit of the earth is between the sun and the orbit of a superior planet, it is possible for the earth to be between the sun and the planet. In this situation the planet and the sun are on opposite sides of the earth, or the planet is in opposition ; thus, if when the earth is at E, Mars be at A, he is then in opposition to the sun.

A superior planet is in quadrature with the sun, when it's geocentric place is 90 degrees from the geocentric place of the sun ; thus if the earth be at E, and Mars at B or C, he is in quadrature with

with the sun; for the lines A E, E B, form a right angle, as do also the lines E A, E C.

As the earth goes round the sun in less time, and in a less orbit than any of the superior planets, it will not be amiss to suppose a superior planet to stand still in some part of it's orbit, while the earth goes once round the sun in her's, and consider the appearances the planets would then have, which are these: 1. While the earth is in her most distant semicircle, the apparent motion of the planet would be direct. 2. While the earth is in her nearest semicircle, the planet would be retrograde. 3. While the earth is near the points of contact of a line drawn from the planet, so as to be a tangent to the earth's orbit, the planet would be stationary.

Let A B C D E F G H, plate VIII. fig. 1, be the orbit of the earth, S the sun, P Q O the orbit of Mars, L M N T an arc of the ecliptic. Let us suppose the planet Mars to continue at P, while the earth goes round in her orbit, according to the order of the letters A B C, &c. A B C D E F G H may be considered as so many stations, from whence an inhabitant of the earth would view Mars at different times of the year; and if straight lines be drawn from each of these stations,

K 4

through

through Mars at P, and continued to the ecliptic, they will point out the apparent place of Mars, at these different stations.

Thus supposing the earth at A, the planet will be seen among the stars at L; when the earth is arrived at B, the planet will appear at M; and in the same manner when at C D and E, it will be seen among the stars at N R T; therefore, while the earth moves over the large part of the orbit A B C D E, the planet will have an apparent motion from L to T, and this motion is from west to east, or the same way with the earth; and the planet is said to move direct, or according to the order of the signs. When the earth is near to A and E, the point of contact of the tangent to the earth's orbit, the planet will be stationary for a short space of time.

When the earth moves from E to H, the planet seems to return from T to N; and while it moves from H to A, it will be retrograde to L, where it will again be stationary: and since the part of the orbit which the earth describes in passing from A to E, is much greater than the part E H P, though the space T L which the planet describes in direct and retrograde motion is the same, the direct motion from L to T must
be

be much slower than the retrograde motion from T to L.

When the earth is at C, a line drawn from C through S and P to the ecliptic, shews that Mars is then in conjunction with the sun. But when the earth is at H, a line drawn from H through P, and continued to the ecliptic, would terminate in a point opposite to S; that is, in this situation Mars would be in opposition to the sun. Thus it appears that the motion of Mars is direct when in conjunction, and retrograde when in opposition.

The retrograde motions of the superior planets happen oftener, the slower their motions are; as the retrograde motion of the inferior planets happen oftener, the swifter their angular motions. Because the retrograde motions of the superior planets depend upon the motions of the earth; but those of the inferior on their own angular motion. A superior one is retrograde once in each revolution of the earth; an inferior one in every revolution of it's own.

The superior planets are sometimes nearer the earth than at other times; they also appear larger, or smaller, according to their different distances from

from us. Thus suppose the earth to be at C; if Mars be at P, he is the whole diameter of the earth's orbit nearer to us, than if he were at V, and consequently his disc must appear larger at V than it would at P; in other places, the distances of Mars from the earth are intermediate.

The diameter of the earth's orbit bears a greater ratio to the diameter of the orbit of Mars, than it does to the diameter of the orbit of Jupiter; and a greater to that of Jupiter, than of Saturn; and consequently the difference between the greatest and least apparent diameters is greater in Mars than in Jupiter, and greater in Jupiter than in Saturn.

The superior, like the inferior planets, do not always appear in the ecliptic, their orbits being inclined also to that of the earth; one-half is therefore above the ecliptic, the other half below it, nor are they ever seen in it but when they are in their nodes.

If, therefore, two planets happen to be in conjunction, at the time they come near the node of one of them, they would be seen from the sun apparently to touch one another; and the farthest of those planets from the sun, would see the
nearest

nearest moving over the face of the sun, like a black spot, being then directly between the sun and the remoter planet. So the planet Venus was observed from the earth, in the transits of the years 1761, and 1769. Also, should an opposition of two planets happen near a node of one of them, the sun being then directly between them, would hide the light of one from the other.

THAT THE PLANETS ARE OPAKE BODIES, AND
DERIVE THEIR LIGHT FROM THE SUN.

That the planets are all opaque, or dark bodies, and consequently shine only by the light they receive from the sun, is plain, because they are not visible when they are in such parts of their orbits as are between the sun and earth, that is, when their illuminated side is turned from us.

The sun enlightens only half a planet at once; the illuminated hemisphere is always that which is turned towards the sun, the other hemisphere of the planet is dark. To speak with accuracy, the sun being larger than any of the planets, will illuminate rather more than half; but this difference, on account of the great distance of the sun from any of the planets, is so great, that it's light
may

may be considered as coming to them in lines physically parallel.

Like other opaque bodies, they cast a shadow behind them, which is always opposite to the sun. The line in the planet's body, which distinguishes the lucid from the obscure part, appears sometimes strait, sometimes crooked. The convex part of the curve is sometimes towards the splendid, and the concave towards that which is obscure, and vice versa, according to the situation of the eye with respect to the planet, and of the sun which enlightens the planet.

Hence the inferior planets going round the sun in less orbits than our earth does, will sometimes have more, sometimes less of their illuminated side towards us; and as it is the illuminated part only which is visible to us, Mercury and Venus will, through a good telescope, exhibit the several appearances of the moon, from a fine thin crescent to the enlightened hemisphere.

If we view Venus through a telescope, when she follows the sun's rays on the eastern side, and appears above the horizon after sun-set, we shall see her appear nearly round, and but small; she is at that time beyond the sun, and presents to us
an

an enlightened hemisphere. As she departs from the sun towards the east, she augments in her apparent size; and on viewing her through a telescope, is seen to alter her figure, abating of her apparent roundness, and appearing successively like the moon, in the different stages of her decrease. At length, when she is at her greatest elongation, she is like the moon in her first quarter, and appears as she does when from a full she has decreased to half a moon.

After this, as she approaches (in appearance) to the sun, she appears concave in her illuminated part, as the moon when she forms a crescent; thus she continues till she is hid entirely in the sun's rays, and presents to us her whole dark hemisphere, as the moon does in her conjunction, no part of the planet being then visible.

After this, when she departs out of the sun's rays on the western side, we see her in the morning, just before day-break. It is in this situation that Venus is called the morning star, as in the other she is called the evening star. She at this time appears very beautiful, like a fine thin crescent; just a verge of silver light is seen on her edge. From this period she grows more and more enlightened every day, till she is arrived at

her greatest digression or elongation, when she again appears as a half moon, or as the moon in her first quarter; from this time, if continued to be viewed with a telescope, she is found to be more and more enlightened, though she is all the while decreasing in magnitude, and thus continues growing smaller and rounder, till she is again hid or lost in the sun's rays.

Fig. 1 and 2, plate IX. represents the orbits of Venus and the earth, with the sun in the center of them. The planet Venus is drawn in eight different situations, with it's illuminated hemispheres towards the sun. If we suppose the earth to be at T, when Venus is at A, her dark hemisphere is towards the earth, and she is therefore invisible, except the conjunction happens in her node, for then she appears like a dark spot upon the disc of the sun. When Venus is at B, a little of her enlightened side is turned towards the earth, and therefore she appears sharp horned; when she is at C, half her enlightened hemisphere is turned towards the earth, and she appears like an half moon; at D, more than half her enlightened hemisphere is towards us, and she appears like the moon about three days before it is full; at E, the whole enlightened hemisphere is towards the earth, Venus is then either behind the
sun,

sun, or so very near him, that she can hardly be seen; but if she could, she would appear round, like the full moon. At F she is like the moon three days after the full; at G like a half moon again; at H like a crescent, with the points of the horns turned the contrary way to what they were at B. All this is equally applicable to Mercury.

Fig. 2, plate VII. exhibits the several appearances of Venus, corresponding to their several situations in the foregoing figure; thus when Venus is at A, fig. 1, she is quite dark, as at A, fig. 2; when she is at B, fig. 1, she appears as at B, fig. 2, &c.

The inferior planets do not shine brightest when they are full; thus Venus does not appear brightest in her superior conjunction, though her illuminated hemisphere be then turned towards us. Her splendor is more diminished by her being at a greater distance from us, than the conspicuous part of her illuminated disc is increased. Dr. Halley has shewn, that Venus is brightest when her elongation from the sun is about 40 degrees. Mercury is in his greatest brightness, when very near his utmost elongation.

The superior planets going round the sun in larger orbits than the earth, always turn much the greater part of their enlightened hemisphere towards it, and therefore appear round, like the full moon, except Mars, who sometimes appears like the moon at a little distance from the full.

Jupiter and Saturn are so remote, that they turn very nearly the same hemisphere towards us that they do towards the sun; for which reason, those planets always appear round through the telescope.

OF THE MOON'S MOTION.

It has been already observed, that four of the primary planets, the earth, Jupiter, Saturn, and the Georgium Sidus, are, in their revolutions round the sun, attended by secondary planets. As the moon turns round the earth, enlightening our nights, by reflecting the light she receives from the sun, so do the other satellites enlighten the planets to which they belong, and move round those planets at different periods of time, proportioned to their several distances; and as the moon keeps company with this earth, in it's annual revolution round the sun, so do they severally accompany the planets to which they belong
in

in their several courses round that luminary.

We shall speak here only of the moon, which of all the heavenly bodies, excepting the sun, is the most splendid and brilliant, the inseparable companion and attendant of our earth.

If we imagine the plane of the moon's orbit to be extended to the sphere of the heaven, it would mark therein a great circle, which may be called the moon's apparent orbit; because the moon appears to the inhabitants of the earth to move in that circle, through the twelve signs of the zodiac, in a periodical month.

Thus let E F G H I, fig. 3, plate XI. be the orbit of the earth, S the sun, a b c d the orbit of the moon, when the earth is at E: let A B C D be a great circle in the sphere of the heaven, in the same plane with the moon's orbit. The moon, by going round her orbit according to the order of letters, appears to an inhabitant of the earth to go round in the great circle A B C D, according to the order of those letters: for when the moon is at a, seen from the earth at E, she appears at A; when the moon is got to b, she appears at B; when to c, she will appear at C;
L
when

when arrived at d, she will appear at D. It is true, when the moon is at b, the visual line drawn from E, through the moon, terminates in L; as it does in M, when the moon is at d; but the lines L M and D B being parallel, and not farther distant from each other than the distance of the earth's orbit, are as to sense coincident, their distance measured in the sphere of the heaven is insensible; for the same reason, though the earth moves from E to F, in the time that the moon goes round her orbit, so that at the end of a periodical month the moon will be at a, and is seen from the earth at F, in the line F N; the moon will, notwithstanding, appear at A, the lines F N and E A being parallel, and as to sense coincident: in like manner, in whatever part of her orbit the earth is, as at H or I, the moon, by going round in her orbit, will appear to an inhabitant of the earth to go round in the great circle A B C D.

The plane of the moon's orbit extended in the heavens, cuts the ecliptic in two opposite points. The two points where the moon's apparent orbit thus cuts the ecliptic, are called the MOON'S NODES. The point where the moon appears to cross the ecliptic, as she goes into north latitude, is called the moon's ascending node, of which
this

this is the character ♄ ; the point where the moon goes into south latitude is her descending node, and is marked thus ♄ ; the moon's ascending node is often called the dragon's head ; her descending node is called the dragon's tail. The line of the moon's node is a line drawn from one node to the other. The moon, therefore, appears in the ecliptic only when she is in one of her nodes ; in all other parts of her orbit she is either in north or south latitude, sometimes nearer to, sometimes further removed from the ecliptic, according as she happens to be more or less distant from the nodes.

The extremities of the line of the nodes are not always directed towards the same points of the ecliptic, but continually shift their places from east to west, or contrary to the order of the signs, performing an entire revolution about the earth, in the space of something less than nineteen years.

When the place in which the moon appears to an inhabitant of the earth, is the same with the sun's place, she is said to be in CONJUNCTION. When the moon's place is opposite to the sun's place, she is said to be in OPPOSITION. When she is a quarter of a circle distant from the sun,

she is said to be in QUADRATURE. Both the conjunction and opposition of the moon are termed SYZGIES.

The common lunar month, or the time that passes between any new moon and the next that follows it, is called A SYNODICAL MONTH, or A LUNATION.

A PERIODIC MONTH is the time the moon takes up to describe her orbit; or in other words, the time in which the moon performs one entire revolution about the earth, from any point in the zodiac to the same again.

If the earth had no revolution round the sun, or the sun no apparent motion in the ecliptic, the periodical and synodical month would be the same; but as this is not the case, the moon takes up a longer time to pass from one conjunction to the next, than to describe it's whole orbit; or the time between one new moon and the next is longer than the moon's periodical time. The difference between those two months is about 2 days, 5 hours.

The moon revolves round the earth from west to east, and the sun apparently revolves round the earth

earth the same way. Now at the new moon, or when the sun and moon are in conjunction, they both set out from the same place, to move the same way round the earth; but the moon moves much faster than the sun, and consequently will overtake it; and when the moon does overtake it, it will be a new moon again.

If the sun had no apparent motion in the ecliptic, the moon would come up to it, or be in conjunction again, after it had gone once round in it's orbit; but as the sun moves forward in the ecliptic, whilst the moon is going round, the moon must move a little more than once round, before it comes even with the sun, or before it comes to conjunction. Hence it is that the time between one conjunction, and the next in succession, is something more than the time the moon takes up to go once round it's orbit; or a synodical month is longer than a periodical one.

In fig. 3, plate IX. let *S* be the sun, *C F* a part of the earth's orbit, *M D* a diameter of the moon's orbit when the earth is at *A*, and *m d* another diameter parallel to the former, when the earth is at *B*. Whilst the earth is at *A*, if the moon be at *D*, she will be in conjunction; and if the earth was to continue at *A*, when the moon

had gone once round it's orbit, from D through M, so as to return to D again, it would again be in conjunction. Therefore, upon the supposition that the earth has no motion in it's orbit, the periodical and synodical months would be equal to one another. But as the earth does not continue at A, it will move forwards in it's orbit, during the revolution of the moon from A to B; and as the moon's orbit moves with it, the diameter MD will then be in the position md; therefore, when the moon has described it's orbit, it will be at d in this diameter md; but if the moon is at d, and the sun at S, the moon will not be in conjunction, consequently the periodical month is completed before the synodical. The moon, in order to come to conjunction, when the earth is at B, must be at e, in the diameter ef; or besides going once round in it's orbit, it must also describe the arc de. The synodical month is, therefore, longer than the periodical, by the time the moon takes up to describe the arc de.

This may be also explained in another manner, by considering the motion of the sun; a view of the subject, that may render it more easy to some young minds than the foregoing. Thus let us suppose the earth at rest at E, fig. 4, plate IX. M the moon in conjunction with the sun at S,
while

while the moon describes her orbit A B C about the earth at E, let the sun advance by his apparent annual motion from S to D. It is plain that the moon will not come in conjunction with the sun again, till, besides describing her orbit, she hath described, over and above, the arch M F, corresponding to the arch S D.

As the moon goes round the earth in a much smaller orbit than that in which the earth revolves round the sun, sometimes more, sometimes less, and sometimes no part of her enlightened half will be towards us; hence the different phases and appearances of the moon.

The full moon, or opposition, is that state in which her whole disk is enlightened, and we see it all bright, and of a circular figure. The new moon is when she is in conjunction with the sun; in this state, the whole surface turned towards us is dark, and she is therefore invisible to us.

The first quarter of the moon she appears in the form of a semicircle, whose circumference is turned towards the west. At the last quarter, she appears again under the form of a semicircle, but with the circumference turned towards the east.

These phases may be illustrated in a very pleasing manner to the pupil, by exposing an ivory ball to the sun, in a variety of positions, by which it may present a greater or smaller part of it's illuminated surface to the observer. If it be held nearly in opposition, so that the eye of the observer may be almost immediately between it and the sun, the greatest part of the enlightened side will be seen; but if it be moved in a circular orbit, towards the sun, the visible enlightened part will gradually decrease, and at last disappear, when the ball is held directly towards the sun. Or to apply the experiment more immediately to our purpose; if the ball, at any time when the sun and moon are both visible, be held directly between the eye of the observer and the moon, that part of the ball on which the sun shines, will appear exactly of the same figure as the moon itself.

The phases of the moon, like those of Venus, may also be illustrated by a diagram; thus in fig. 1, plate XI. let S be the sun, T the earth, A B C D E F G H the orbit of the moon. The first observation to be deduced from this figure, is, that the half of the earth and moon which is towards the sun, is wholly enlightened by it; and the other half, which is turned from it, is totally dark.

dark. When the moon is in conjunction with the sun at A, her enlightened hemisphere is turned towards the sun, and the dark one towards the earth; in which case, we cannot see her, and it is said to be new moon. When the moon has moved from A to B, a small portion a b of her enlightened hemisphere will be turned towards the earth; which portion will appear of the form represented at B, fig. 2, plate XI. (a figure which exhibits the phases as they appear to us).

As the moon proceeds in her orbit, according to the order of the letters, more and more of her enlightened part is turned towards the earth. When she arrives at C, in which position she is said to be in quadrature, one-half of that part towards the earth is enlightened, appearing as at C among the phases; this appearance is called a half moon. When she comes to D, the greatest part of that half which is towards us is enlightened; the moon is then said to be gibbous, and of that figure which is seen at D, in fig. 2.

When the moon comes to E, she is in opposition to the sun, and consequently turns all her illuminated surface towards the earth, and shines with a full face, for which reason she is called a
full

full moon. As she passes through the other half of her orbit, from E by F G, and H to A again, she puts on the same faces as before, but in a contrary order or position.

As the moon, by reflected light from the sun, illuminates the earth, so the earth does more than repay her kindness, in enlightening the surface of the moon, by the sun's reflex light, which she diffuses more abundantly upon the moon, than the moon does upon us; for the surface of the earth is considerably greater than that of the moon, and consequently if both bodies reflect light in proportion to their size, the earth will reflect much more light upon the moon, than it receives from it.

In new moon, the illuminated side of the earth is fully turned towards the moon, and the Lunarians will have a full earth, as we, in a similar position, have a full moon. And from thence arises that dim light which is observed in the old and new moons, whereby, besides the bright and shining horns, we can perceive the rest of her body behind them, though but dark and obscure. Now when the moon comes to be in opposition to the sun, the earth, seen from the moon, will appear in conjunction with him, and it's dark side

side will be turned towards the moon, in which position the earth will be invisible to the Lunarians; after this, the earth will appear to them as a crescent. In a word, the earth exhibits the same appearance to the inhabitants of the moon, that the moon does to us.

The moon turns about it's own axis in the same time that it moves round the earth; it is on this account that she always presents the same face to us: for by this motion round her axis, she turns just so much of her surface constantly towards us, as by her motion about the earth would be turned from us.

This motion about the axis is equable and uniform, but that about the earth is unequal and irregular, as being performed in an ellipsis, consequently the same precise part of the moon's surface can never be shewn constantly to the earth; which is confirmed by a telescope, by which we often observe a little segment on the eastern and western limb, appear and disappear by turns, as if her body librated to and fro; this phænomenon is called the moon's libration. The lunar motions are subject to several other irregularities, which are fully discussed in the larger works on astronomy.

OF ECLIPSES.

Those phænomena that are termed eclipses, were in former ages beheld with terror and amazement, and looked upon as prodigies that portended calamity and misery to mankind. These fears, and the erroneous opinions which produced them, had their source in the hieroglyphical language of the first inhabitants of the earth. We do not, however, imagine that even the most ancient of these knew any more of the laws and motions of the heavenly bodies, than what could be discovered from immediate sight; or that they knew enough of the lunar system to calculate an eclipse, or even that they ever attempted it.

The word ECLIPSE is derived from the Greek, and signifies dereliction, a fainting away, or swooning. Now as the moon falls into the shadow of the earth, and is deprived of the sun's enlivening rays, at the time of her greatest brightness, and even appears pale and languid before her obscuration, lunar eclipses were called LUNÆ LABORES, the struggles or labours of the moon; to relieve her from these imagined distresses, superstition adopted methods as impotent as they were absurd.

When

When the moon, by passing between us and the sun, deprived the earth of it's light and heat, the sun was thought to turn away his face, as if in abhorrence of the crimes of mankind, and to threaten everlasting night and destruction to the world. But thanks to the advancement of science, which, while it has delivered us from the foolish fears and idle apprehensions of the ancients, leaves us in possession of their representative knowledge, enables us to explain the appearances on which it was founded, and points out their perversion and abuse of it.

Any opake body that is exposed to the light of the sun, will cast a shadow behind it. This shadow is a space deprived of light, into which if another body comes, it cannot be seen for want of light; the body thus falling within the shadow, is said to be ECLIPSED.

Hence there must be three bodies concerned in an eclipse; 1. the luminous body; 2. the opake body, that casts the shadow; and, 3. the body involved in the shadow.

OF ECLIPSES OF THE MOON.

As the earth is an opaque body, enlightened by the sun, it will cast a shadow towards those parts that are opposite to the sun, and the axis of this shadow will always be in the plane of the ecliptic, because both the sun and the earth are always there.

The sun and the earth are both spherical bodies; if they were, therefore, of an equal size, the shadow of the earth would be cylindrical, as in fig. 5, plate IX. and would continue of the same breadth at all distances from the earth, and would consequently extend to an infinite distance, so that Mars, Jupiter, or Saturn, might be eclipsed by it; but as these planets are never eclipsed by the earth, this is not the shape of the shadow, and consequently the earth is not equal in size to the sun.

If the sun were less than the earth, the shadow would be wider, the farther it was from the earth, see fig. 6, plate IX. and would therefore reach to the orbits of Jupiter and Saturn, and eclipse any of these planets when the earth came between the sun and them; but the earth never eclipses them, therefore this is not the shape of it's shadow,

shadow, and consequently the sun is not less than the earth.

As we have proved that the earth is neither larger nor equal to the sun, we may fairly conclude that it is less; and that the shadow of the earth is a cone, which ends in a point at some distance from the earth, see fig. 7, plate IX.

The axis of the earth's shadow falls always upon that point of the ecliptic that is opposite to the sun's geocentric place; thus if the sun be in the first point of Aries, the axis of the earth's shadow will terminate in the first point of Libra. It is clear, therefore, that there can be no eclipse of the moon but when the earth is interposed between it and the sun, that is, at the time of it's opposition, or when it be full; for unless it is opposite to the sun, it can never be in the earth's shadow: and if the moon did always move in the plane of the ecliptic, she would every full moon pass through the body of the shadow, and there would be a total eclipse of the moon.

We have already observed, that the moon's orbit is inclined to the plane of the ecliptic, and only coincides with it in two places, which are termed

termed the nodes. It may, therefore, be full moon* without her being in the plane of the ecliptic; she may be either on the north or the south side of it; in either of these cases, she will not enter into the shadow, but be above it in the one, below it in the other.

Let H G represent the orbit of the moon, E F the plane of the ecliptic, in which the center of the earth's shadow always moves, and N the node of the moon's orbit; A B C D four places of the shadow of the earth in the ecliptic. When the shadow is at A, and the moon at I, there will be no eclipse; when the full moon is nearer the node, as at K, only part of her globe passes through the shadow, and that part becoming dark, it is called a PARTIAL ECLIPSE; and it is said to be of so many digits as there are twelfth parts of the moon's diameter darkened.

When

* A planet may be in opposition to, or conjunction with the sun, without being in a right line that passes through the sun and the earth. Astronomers term it in conjunction with the sun, if it be in the same part of the zodiac; in opposition, if it be in a part of the zodiac, 180 degrees from the sun.

When the full moon is at M, she enters into the shadow C, and passing through it becomes wholly darkened at L, and leaves the shadow at O; as the whole body of the moon is here immersed in the shade, this is called a TOTAL ECLIPSE.

But when the moon's center passes through that of the shadow, which can only happen when she is in the node at N, it is called a TOTAL AND CENTRAL ECLIPSE. There will always be such eclipses, when the center of the moon, and axis of the shadow, meet in the nodes.

The duration of a central eclipse is so long, as to let the moon go the length of three of it's diameters totally eclipsed, which stay in the earth's shadow is computed to be about four hours; whereof the moon takes one hour from it's beginning to enter the shadow, till quite immersed therein; two hours more she continues totally dark; and the fourth hour is taken up from her first beginning to come out of the shadow, till she is quite out of it.

In the beginning of an eclipse, the moon enters the western part of the shadow with the eastern part of her limb, and in the end of it she leaves

M

the

the eastern part of the shadow with the western part of her limb ; all the intermediate time, from her entrance to her quitting the shadow, is reckoned into the eclipse ; but only so much into the total immersion, as passes while the moon is altogether obscured.

From the magnitude of the sun, the size of the earth, their distance from each other, the refraction of the atmosphere, and the distance of the moon from the earth ; it has been calculated that the shadow of the earth terminates in a point, which does not reach so far as the moon's orbit. The moon is not, therefore, eclipsed by the shadow of the earth alone. The atmosphere, by refracting some of the rays of the sun, and reflecting others, casts a shadow, though not so dark a one as that which arises from an opaque body ; when, therefore, we say that the moon is eclipsed, by passing into the shadow of the earth, it is to be understood of the shadow of the earth, together with it's atmosphere. Hence it is that the moon is visible in eclipses, the shadow cast by the atmosphere not being so dark as that cast by the earth. The cone of this shadow is larger than the cone of the earth's shadow, the base thereof broader, the axis longer.

All opake bodies, when illuminated by the rays of the sun, cast a shadow from them, which is encompassed by a *PENUMBRA*, or thinner shadow, which every where furrounds the former, growing larger and larger as we recede from the body : in other words, the penumbra is all that space furrounding the shadow, into which the rays of light can only come from some part of that half of the globe of the sun, which is turned towards the planet, all the rest being intercepted by the intervening body.

Let S, fig. 2, plate XI. be the sun, E the planet, then the penumbral cone is F H G. The nearer any part of the penumbra is to the shadow, the less light it receives from the sun ; but the further it is, the more it is enlightened ; thus the parts of the penumbra near M are illuminated by those rays of light which come from that part of the sun near to I, all the rest being intercepted by the planet E ; in like manner, the parts about N can only receive the light that comes from the part of the sun near to L, whereas the parts of the penumbra at P and Q are enlightened in a much greater degree : for the planet intercepts from P only those rays which come from the sun near L, and hides from Q only a small part of the sun near I.

The moon passes through the penumbra before she enters into the shadow of the atmosphere; this causes her gradually to lose her light, which is not sensible at first, but as she goes into the darker part of the penumbra, she grows paler; the penumbra, where it is contiguous to the shadow, is so dark, that it is difficult to distinguish one from the other.

The moon, in a total eclipse, generally appears of a dusky reddish colour, especially towards the edges; but of a darker towards the middle of the shadow.

OF ECLIPSES OF THE SUN.

The moon, when in conjunction, if near one of her nodes, will be interposed between us and the sun, and will consequently hide the sun, or a part of him, from us, and cast a shadow upon the earth: this is called an ECLIPSE OF THE SUN; it may be either partial or total.

An eclipse of any lucid body, is a deficiency or diminution of light, which would otherwise come from it to our eye, and is caused by the interposition of some opaque body.

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The eclipses of the sun and moon, though expressed by the same word, are in nature very different; the sun, in reality, loses nothing of it's native lustre in the greatest eclipses, but is all the while incessantly sending forth streams of light every way round him, as copiously as before. Some of these streams are, however, intercepted in their way towards our earth, by the moon coming between the earth and the sun; and the moon having no light of her own, and receiving none from the sun on that half of the globe which is towards our eye, must appear dark, and make so much of the sun's disk appear so, as is hid from us by her interposition.

What is called an eclipse of the sun, is therefore, in reality, an eclipse of the earth, which is deprived of the sun's light, by the moon's coming between, and casting a shadow upon it. The earth being a globe, only that half of it which at any time is turned towards the sun, can be enlightened by him at that time; it is upon some part of this enlightened half of the earth, that the moon's shadow, or penumbra, falls in a solar eclipse.

The sun is always in the plane of the ecliptic; but the moon being inclined to this plane, and

only coinciding with it at the nodes, it will not cover either the whole or a part of the sun; or in other words, the sun will not be eclipsed, unless the moon at that time is in or near one of her nodes.

The moon, however, cannot be directly between the sun and us, unless they are both in the same part of the heavens; that is, unless they are in conjunction. Therefore, the sun can never be eclipsed but at the new moon, nor even then, unless the moon at that time is in or near one of her nodes.

From hence it is easy to shew, that the darkness at our Saviour's crucifixion was not owing to an eclipse of the sun. For the crucifixion happened at the time of the Jewish passover, and the passover, by the appointment of the law, was to be celebrated at the full moon; the sun could not, therefore, be eclipsed at the time of the passover. An intelligent tutor will find many opportunities of observing to his pupil, that nature, and philosophy, which explains the phænomena of nature, do always agree with divine revelation.

The moon being much smaller than the earth, and having a conical shadow, because she is less
than

than the sun, can only cover a small part of the earth by her shadow ; though, as we have observed before, the whole body of the moon may be involved in that of the earth. Hence an eclipse of the sun is visible but to a few inhabitants of the earth ; whereas, an eclipse of the moon may be seen by all those that are on that hemisphere which is turned towards it.

It is not necessary, in order to constitute a CENTRAL eclipse of the sun, that the moon should be exactly in the line of the nodes, at the time of it's conjunction ; for it is sufficient to denominate an eclipse of the sun CENTRAL, that the center of the moon be directly between the center of the sun, and the eye of the spectator ; for to him, the sun is then centrally eclipsed. But as the shadow of the moon can cover but a small portion of the earth, it is obvious this may happen when the moon is not in one of her nodes. Further, the sun may be eclipsed centrally, totally, partially, and not at all at the same time.

Thus in fig. 3, plate XI. let A B C be the sun, M N the moon, h l g part of the cone of the moon's shadow, f d the penumbra of the moon : from this figure it is easy to perceive,

1. That those parts of the earth that are within the circle represented by $g h$, are covered by the shadow of the moon, so that no rays can come from any part of the sun into that circle, on account of the interposition of the moon.

2. In those parts of the earth where the penumbra falls, only part of the sun is visible; thus between d and g , the parts of the sun near C cannot be seen, the rays coming from thence towards d or g being intercepted by the moon; whereas at the same time, the parts between f and h are illuminated by rays coming from C , but are deprived by the moon of such as come from A .

3. The nearer any part of the earth, within the penumbra, is to the shadow of the moon, as in places near g , l , or h , the less portion of the sun is visible to its inhabitants; the nearer it is to the outside of the penumbra, as towards d , e , or f , the greater portion of the sun may be seen.

4. Out of the penumbra, the entire disk of the sun is visible.

OF PARALLAX AND REFRACTION.

Astronomy is subject to many difficulties, besides those which are obvious to every eye. When we look at any star in the heavens, we do not see it in it's real place ; the rays coming from it, when they pass out of the purer ethereal medium, into our coarser and more dense atmosphere, are REFRACTED, or bent in such a manner, as to shew the star higher than it really is. Hence we see all the stars before they rise, and after they set ; and never, perhaps, see any one in it's true place in the heavens.

There is another difference in the apparent situation of the heavenly bodies, which arises from the stations in which an observer views them. This difference in situation is called the PARALLAX of an object.

The parallaxes principally used by astronomers, are those which arise from considering the object as viewed from the centers of the earth and the sun, from the surface and center of the earth, and from all three compounded.

The difference between the place of a planet, as seen from the sun, and the same as seen from
the

the earth, is called the parallax of the annual orbit; in other words, the angle at any planet, subtended between the sun and the earth, is called the parallax of the earth's or annual orbit.

The diurnal parallax is the change of the apparent place of a fixed star, or planet, of any celestial body, arising from it's being viewed on the surface, or from the center of the earth.

The fixed stars have no diurnal parallax, the moon a considerable one; that of the planets is greater or less, according to their distances.

Let H S W, fig. 2, plate VIII. represent the earth, T the center thereof, o R G part of the moon's orbit, P r g part of a planet's orbit, Z a A part of the starry heavens. Now to a spectator at S, upon the surface of the earth, let the moon appear in G, that is, in the sensible horizon of S, and it will be referred to A; but if viewed from the center T, it will be referred to the point D, which is it's true place.

The arc A D will be the moon's parallax; the angle S G T the parallactic angle; or the parallax is expressed by the angle under which the
femi-

femidiameter TS of the earth is seen from the moon.

If the parallax be considered with respect to different planets, it will be greater or less, as those objects are more or less distant from the earth; thus the parallax AD of G is greater than the parallax ad of g .

If it be considered with respect to the same planet, it is evident that the horizontal parallax (or the parallax when the object is in the horizon) is greatest of all, and diminishes gradually, as the body rises above the horizon, until it comes to the zenith, where the parallax vanishes, or becomes equal to nothing. Thus AD and ad , the horizontal parallaxes of G and g , are greater than aB and ab , the parallaxes of R and r ; but the objects O and P , seen from S or T , appear in the same place Z , or the zenith.

By knowing the parallax of any celestial object, it's distance from the center of the earth may be easily obtained by trigonometry. Thus if the distance of G from T be sought, in the triangle STG , ST being known, and the angle SGT determined by observation, the side TG is thence known.

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The parallax of the moon may be determined by two persons observing her from different stations at the same time, she being vertical to the one, and horizontal to the other. It is generally concluded to be about 57 minutes of a degree.

But the parallax most wanted, is that of the sun, whereby his absolute distance from the earth would be known; and hence the absolute distances of all the other planets would be also known, from the second Keplerian law.

As one of the principal objects of astronomy is to fix the situation of the several heavenly bodies, it is necessary, as a first step, to understand the causes which occasion a false appearance of the place of those objects, and make us suppose them in a different situation from that which they really have. Among these causes, REFRACTION is to be reckoned. By this term is meant, the bending of the rays of light as they pass out of one medium into another.

The earth is every where surrounded by an heterogeneous fluid, a mixture of air, vapour, and terrestrial exhalations, that extend to the regions of the sky. The rays of light from the sun, moon, and stars, in passing to a spectator
upon

upon earth, come through this medium, and are so refracted in their passage through it, that their apparent altitude is greater than their true altitude.

Let A C, fig. 3, plate VIII. represent the surface of the earth, T it's center, B P a part of the atmosphere, H E K the sphere of the fixed stars, A F the sensible horizon, G a planet, G D a ray of light proceeding from the planet to D, where it enters our atmosphere, and is refracted towards the line D T, which is perpendicular to the surface of the atmosphere; and as the upper air is rarer than that near the earth, the ray is continually entering a denser medium, and is every moment bent towards T, which causes it to describe a curve as D A, and to enter a spectator's eye at A, as if it came from E, a point above G. And as an object always appears in that line in which it enters the eye, the planet will appear at E, higher than it's true place, and frequently above the horizon A F, when it's true place is below it at G.

This refraction is greatest at the horizon, and decreases very fast as the altitude increases, inso-much that the refraction at the horizon differs from the refraction at a very few degrees above
the

the horizon, by about one-third part of the whole quantity. At the horizon, in this climate, it is found to be about 33 minutes. In climates nearer to the equator, where the air is purer, the refraction is less; and in the colder climates, nearer to the pole, it increases exceedingly, and is a happy provision for lengthening the appearance of the light at those regions so remote from the sun.

Gaffendus relates, that some Hollanders who wintered in Nova Zembla, in latitude 75° , were surprized with a sight of the sun 17 days before they expected him in the horizon. This difference was owing to the refraction of the atmosphere in that latitude. To the same cause, together with the peculiar obliquity of the moon's orbit to the ecliptic, some of these very northern regions are indebted for an uninterrupted light from the moon much more than half the month, and sometimes almost as long as it is capable of affording any light to other parts of the earth. Hence, in—

“ Those regions, where no green herb appeareth, and which for months behold not the light of the sun, nor the chearful day :

“ Infinite

“ Infinite wisdom is manifested, and abundant means of solace are offered to the contented soul.

“ He murmureth not that the sun is hid from him.

“ He knoweth that the moon will give light for many days, and doth not fear the approach of thick darkness.

“ To him the sun returneth at the appointed season ; but it's approach is hastened by the refraction of the atmosphere.” *

To this refraction we must attribute another curious phænomenon, mentioned by Pliny : for he relates, that the moon had been eclipsed once in the west, at the same time that the sun appeared above the horizon in the east. Mæstlinus, in Kepler, speaks of another instance of the same kind, which fell under his own observation.

Through this refraction we are favoured with the sight of the sun, about 3 minutes and $\frac{1}{4}$ before it rises above the horizon ; and also as much every

* King's Hymns to the Supreme Being.

every evening after it sets below it,' which in one year amounts to more than 40 hours.

It is to this property of refraction that we are also indebted for that enjoyment of light from the sun when he is below the horizon, which produces the morning and evening twilight. The sun's rays, in falling upon the higher part of the atmosphere, are reflected back to our eyes, and form a faint light, which gradually augments till it becomes day. Had no such atmosphere existed, the rays of light would have come to us in straight lines, and the appearance and disappearance of the sun would have been instantaneous; we should have had a sudden transition from the brightest sunshine, to the most profound darkness; and from thick darkness to a blaze of light. Thus by refraction we are prepared gradually for the light of the sun, the duration of it's light is prolonged, and shades of darkness softened.

OF THE SATELLITES OF JUPITER AND SATURN.

The existence of the satellites of any of the planets, except the moon, would have been unknown to us without the use of the telescope. The satellites are distinguished according to their places, into first, second, &c. the first being
that

that which is nearest to the planet. The following table shews the time taken by each fatellite in it's revolution ; and also it's mean distance from the primary in semi-diameters thereof.

JUPITER'S SATELLITES.

I.			II.			III.			IV.		
d.	h.	m.	d.	h.	m.	d.	h.	m.	d.	h.	m.
1	18	28	3	13	18	7	3	59	16	18	5

DISTANCE FROM JUPITER IN SEMI-DIAMETERS.

I.	II.	III.	IV.
$5\frac{2}{3}$	9	$14\frac{1}{3}$	$25\frac{1}{3}$

SATURN'S SATELLITES.

I.			II.			III.			IV.			V.		
d.	h.	m.	d.	h.	m.	d.	h.	m.	d.	h.	m.	d.	h.	m.
1	21	18	2	17	41	3	12	25	15	22	41	79	7	48

DISTANCE FROM SATURN IN SEMI-DIAMETERS.

I.	II.	III.	IV.	V.
$8\frac{7}{8}$	$11\frac{1}{4}$	15	36	108

The system of Jupiter and his satellites is very large in itself; yet on account of its immense distance from us, it appears to occupy but a small space in the sphere of the starry heavens, and consequently every satellite of Jupiter appears to us always near its primary, and to have an oscillatory motion, like that of a pendulum going alternately from its greatest digression on one side the planet, to its greatest on the other, sometimes in a straight line, at others in an elliptic curve.

When a satellite is in its superior semicircle, or that half of its orbit that is more distant from the earth than Jupiter, its motion appears direct to us; when a satellite is in its inferior semicircle, nearer to us than Jupiter is, the apparent motion of it is retrograde.

The satellites of Saturn revolve about it in almost the same plane, namely, that of its ring, excepting the fifth, the plane of whose orbit deviates a little therefrom. Those of Jupiter move also in a plane very nearly coincident with that in which Jupiter moves about the sun.

The satellites, and their primaries, mutually eclipse each other in the same manner in which it
has

has been shewn that the earth and the moon does. But there are three cases in which the satellites disappear to us.

The one is, when the satellite is directly behind the body of it's primary, with respect to the EARTH; this is called an OCCULTATION of the planet.

Another is, when it is directly behind it's primary, with respect to the SUN, and so falls into it's shadow, and suffers an eclipse, as the moon, when the earth is interposed between that and the sun.

The last is, when it is interposed between the earth and it's primary; for then it cannot be distinguished from the primary itself.

By observing the eclipses of Jupiter's satellites, it was discovered that light is not propagated instantaneously, though it moves with an incredible velocity; so that light reaches from the sun to us in the space of eleven minutes of time, at more than the rate of 100,000 miles in a second.

OF THE FIXED STARS.

No part of the universe gives such enlarged ideas of the structure and magnificence of the heavens, as the consideration of the number, magnitude, and distance of the fixed stars. We admire indeed, with propriety, the vast bulk of our own globe; but when we consider how much it is surpassed by most of the heavenly bodies, what a point it degenerates into, and how little more, even the vast orbit in which it revolves, would appear, when seen from some of the fixed stars, we begin to conceive more just ideas of the extent of the universe, and of the boundaries of creation.

Among the many distinctions that characterize the fixed stars from the other luminaries of heaven, that which is afforded by their light, or peculiar lustre, is the most obvious.

The light of the planets is steady, because it is reflected; that of the stars is bright and lively, and accompanied with a kind of vibration of light, which we call twinkling. This is supposed to arise from the nature of their light as intrinsic, and not received and reflected, and principally from the smallness of their apparent diameter.

Our atmosphere is full of innumerable little particles, which are continually floating in it ; many of these are large enough, on coming between the eye and such a point as a fixed star, to hide that point, or take that star out of our view, by intercepting it's rays. But these atoms are in perpetual motion, so that the star is no sooner hid by one of them, than it appears again, because the atom has changed it's place ; then another comes, and again intercepts the view : the swift succession of these moving particles, greatly assists in causing that appearance which we term twinkling.

The most conspicuous and brightest of the fixed stars of our horizon is Syrius. The earth, in moving round the sun, is 190 millions of miles nearer to this star in one part of it's orbit, than in the opposite ; yet the magnitude of the star does not appear to be in the least altered, or it's distance affected by it ; so that the distance of the fixed stars is great beyond all computation. The unbounded space appears filled at proper distances with these stars, each of which is probably a sun, with attendant planets rolling round it. In this view, what, and how amazing, is the structure of the universe !

Though the fixed stars are the only marks by which astronomers are enabled to judge of the course of the moveable ones, and we have asserted their relative positions do not vary ; yet this assertion must be confined within some limits, for many of them are found to undergo particular changes, and perhaps the whole are liable to some peculiar motion, which connects them with the universal system of created nature. Dr. Herschel even goes so far as to suppose that there is not, in strictness of speaking, one fixed star in the heavens ; but that there is a general motion of all the starry systems, and consequently of the solar one among the rest.

There are some stars, whose situation and place were heretofore known, and marked with precision, that are no longer to be seen ; new ones have also been discovered, that were unknown to the ancients, while numbers seem gradually to vanish. There are others which are found to have a periodical increase and decrease of magnitude ; and it is probable, that the instances of these changes would have been more numerous, if the ancients had possessed the same accurate means of examining the heavens, as are used at present.

New stars offer to the mind a phænomenon more surprizing, and less explicable, than almost any other in the science of astronomy. I shall select a few instances of the more remarkable ones, for the instruction of the young pupil: a consideration of the changes that take place, at so immense a distance as the stars are known to be from him, may elevate his mind to consider the immensity of HIS power, who regulates and governs all these wide extended motions; “who hath measured the waters in the hollow of his hand, and meted out heaven with a span.”

It was a new star, discovered by Hipparchus, the chief of the ancient astronomers, that induced him to compose a catalogue of the fixed stars, that future observers might learn from his labours, whether any of the known stars disappear, or new ones were produced. The same motives engaged the illustrious Tycho Brahe to form, with unremitting labour and assiduity, another new catalogue of the stars.

Of new stars, the first of which we have a good account, is that which was discovered in the constellation Cassiopea, in the month of November of the year 1572, a time when astronomy was sufficiently cultivated, to enable the astronomers

to give the account with precision. It remained visible about sixteen months; during this time, it kept it's place in the heavens, without the least variation. It had all the radiance of the fixed stars, and twinkled like them; and was in all respects like Sirius, excepting that it surpassed it in brightness and magnitude. It appeared larger than Jupiter, who was at that time in his perigee; and was scarce less bright than Venus.

It was not by degrees that it acquired this diameter, but shone forth at once of it's full size and brightness, as if of instantaneous creation. It continued about three weeks in full and entire splendor, during which time it might be seen even at noon day, by those who had good eyes, and knew where to look for it. Before it had been seen a month, it became visibly smaller, and from thence continued diminishing in magnitude till March, 1574, when it entirely disappeared. As it decreased in size, it varied in colour; at first, it's light was white, and extremely bright; it then became yellowish, afterwards of a ruddy colour, like Mars; and finished with a pale livid white, resembling that of Saturn.

In 1596, Fabricius observed a new star in the neck of the Whale: he first saw it in August, and it disappeared in October of the same year. In 1637, Phocyllides Holwarda observed it again, and not knowing that it had been seen before, took it for a new discovery: he watched it's place in the heavens, and saw it appear again the succeeding year, nine months after it's disappearance. It has been since found to be every year very regular in it's period, except that in 1672 it was missed by Hevelius, and not seen again till 1676. Bullialdus having compared together the observations which had been made of it from 1638 to 1666, determined the periodical time between this star's appearing in it's greatest brightness, and returning to it again, to be 333 days; observing further, that this star did not appear at once in it's full magnitude, or brightness, but by degrees arrived at them. He also framed an hypothesis, to account for these periodic changes.

Three changeable, or re-apparent stars, have been discovered in the constellation of the Swan; the first was seen by Jansonius, in 1600; the second was discovered in 1670; the third by Kirchius, in 1686.

In the latter end of September, 1604, a new star was discovered near the heel of the right foot of *Serpentarius*. There were in that part of the heavens, at that time, the three superior planets, which so engaged the attention of astronomers, that no appearance thereabouts could have long escaped them. Kepler, in describing it, says, that it was precisely round, without any kind of hair, or tail; that it was exactly like one of the stars, except that in the vividness of its lustre, and the quickness of its sparkling, it exceeded any thing he had ever seen before. It was every moment changing into some of the colours of the rainbow, as yellow, orange, purple, and red; though it was generally white, when it was at some distance from the vapours of the horizon. Those in general who saw it, agreed that it was larger than any other fixed star, or even any of the planets, except *Venus*: it preserved its lustre and size for about three weeks; from this time it grew gradually smaller. Kepler supposes that it disappeared some time between October, 1605, and the February following, but on what day is uncertain.

Besides these several re-apparent stars, so well characterized and established by the earliest among the modern astronomers, there have been
many

many discovered since, by Cassini, Maraldi, and others; Mr. Montanere speaks of having observed above one hundred changes among the fixed stars.

The star Algol, in Medusa's head, has been observed long since to appear of different magnitudes, at different times. The period of it has been lately settled by J. Goodricke, Esq. of York. It periodically changes from the first to the fourth magnitude; the time employed from one greatest diminution to the other, was anno 1783, at a mean 2 days, 20 hours, 49 minutes, 3 seconds. The changes are thus: during four hours it gradually diminishes in lustre; during the succeeding four hours, it recovers its first magnitude by a like gradual increase; and during the remaining part of the period, namely, 2 days, 12 hours, 49 minutes, 3 seconds, it invariably preserves its greatest lustre; after the expiration of which term, the diminution again commences.

The causes of these appearances cannot be assigned at present, with any degree of probability; perhaps they have some analogy to the spots on the sun, which at some times appear in greater numbers than at others, some of them bigger than the whole earth; or perhaps they are
owing

owing to some real motions of the stars themselves.

There are several stars that appear single to the naked eye, which are, on examination with a telescope, found to consist of two, three, &c. The number of double stars observed before the time of Dr. Herschel, was but small; but this celebrated astronomer has noted upwards of four hundred; among these, some that are double, others that are treble, double double, quadruple, double treble, and multiple; his catalogue gives the comparative size of these stars, their colour as they appeared to him, with several other very curious particulars.

Besides these phænomena, there are many NEBULÆ, or parts of the heavens, which are brighter than the rest. “The most obvious to common notice, is that large irregular band which crosses the ecliptic in Cancer and Capricorn, and is inclined to it in an angle of about sixty degrees. Other nebulae are seldom so large as to be seen by the naked eye, to which they appear as small stars. Viewed by a telescope, they appear as so many luminous spots, of various figures, in some instances with stars in them; such of these nebulous stars as are visible to the
naked

naked eye, appear as a kind of fine white cloud. The number of *nebulæ* ascertained before the time of Herschel, are about 103." He has, however, given us a catalogue of 1000 new *nebulæ*; many of the *nebulæ* are resolvable by the telescope, into clusters of small stars; and it is found, that telescopes of greater force resolve those *nebulæ* into stars, which appear as white clouds in instruments of less force. Hence then there is reason to conclude, that they all consist of clusters, or prodigious aggregates of stars. Dr. Herschel says, that in the most crowded part of the milky way, he had fields of view, that contained no less than 588 stars, and these were continued for many minutes, so that in one quarter of an hour there passed no less than 116,000 stars through the field of view of his telescope. The blended lustre of these luminous points, is the cause of that light and white appearance, from whence this space has been denominated.

Dr. Herschel endeavours to make it appear, both from observation and well grounded conjecture, 1. That the starry heaven is replete with *nebulæ*, or systems of stars of various figures; and that the milky way is that particular nebula in which our sun is placed. 2. That each nebula is composed of a prodigious number of suns,

or bodies, that shine by their own native splendor.
3. That each individual sun is destined to give light to hundreds of worlds that revolve about it, but which can no more be seen by us, on account of their great distance, than the solar planets can be seen from the fixed stars. Nor is it necessary that in this explored and unexplorable abyss of space, the planets should be of the same magnitude as those that belong to our system; for it is not improbable, but that planetary bodies may be discovered among the double and triple stars.

Dr. Herschel mentions some other heavenly bodies discovered by him, which, from the singularity of their appearance, he finds it difficult to know how to class: he has termed them planetary nebulæ, for he can hardly suppose them to be nebulæ; their light is so uniform, as well as vivid; their diameter so small, and well-defined; if nebulæ, they must consist of stars that are compressed and accumulated in the highest degree.

OF THE TELESCOPIC APPEARANCE OF THE
PLANETS.

By means of the telescope, we are enabled, in some measure, to ascend into the celestial region, and view the sun, moon, and stars, as they would appear to us if they were brought so many times nearer to us as the telescope magnifies; the light proceeding from the luminary we are looking at, being diminished in the same proportion.

The telescope is one of those discoveries, of which no idea could have been formed, previous to the period in which the Supreme Being was pleased to unveil to the human mind some of the mysterious powers of glass: the importance of this discovery, and the extent to which it may be carried, still lie hid among the secrets of infinite wisdom.

When we look at the sun through a telescope even of moderate power, the eye being defended by a piece of coloured or smoked glass, nay, even by the naked eye, when guarded in the same manner, we discover on his surface many black, or rather less bright spots, of various sizes and shapes. Sometimes these spots will vanish in a very short time after their first appearance; some-
times

times they travel over his whole disk, or visible surface, from west to east, when they disappear, and in twelve or thirteen days they appear again, so as to be known, by their magnitude and figure, to be those that had disappeared before. Those, however, which are of the longest continuance, do not appear to have much solidity of consistence, for in a little time they also vanish, and become bright like the rest of the surface.

These spots are more frequent at some periods than at others; in some years, the sun's disk has for many months been perfectly free from them; in others, he has for months been more or less obscured by spots: the most remarkable phenomena of these spots, as observed by Scheiner and Hevelius, are as follow: 1. Every spot, which has a nucleus, or dark part, hath also an umbra, or fainter shade, surrounding it. 2. The boundary betwixt the nucleus and umbra is always distinct and well-defined. 3. The increase of a spot is gradual, the breadth of the nucleus and umbra dilating at the same time. 4. In like manner, the decrease of a spot is gradual, the breadth of the nucleus and umbra diminishing at the same time. 5. The exterior boundary of the umbra never consists of sharp angles, but is always curvilinear, how irregular soever the outside
of

of the nucleus may be. 6. The nucleus of a spot, whilst on the decrease, often changes it's figure, by the umbra incroaching irregularly upon it, insomuch that in a small space of time new incroachments are discernible, whereby the boundary between the nucleus and the umbra is perpetually varying. 7. It often happens, that by these incroachments the nucleus of a spot is divided into two or more nuclei. 8. The nuclei of the spots vanish before the umbra. 9. Small umbræ are often seen without nuclei. 10. A large umbra is seldom seen without a nucleus in the middle of it. 11. When a spot, which consisted of a nucleus and an umbra, is about to disappear, if it be not succeeded by a facula, or spot, brighter than the rest of the disk, the place it occupied is in a very little time not to be perceived.

In the *Philos. Trans.* vol. lxiv. the reader will find several curious observations on these spots, by Professor Wilson, and the Rev. Mr. Wollaston. The latter gentleman says, he once saw, with a twelve-inch reflector, a spot burst to pieces, while he was looking at the sun; the appearance was to him as that of a piece of ice, when dashed on a frozen pond, which breaks to pieces, and slides in various directions.

The spots are by no means confined to one part of the sun's disk, though we do not know that any have been observed about his polar regions. Though their direction is from east to west, yet the paths they describe in their course over the disk, are exceedingly different, sometimes being in strait lines, sometimes in curves; at one time descending from the northern to the southern part of the disk, at other times ascending from the southern to the northern part.

The larger spots, most of which exceed the whole earth in apparent magnitude, last a considerable time, sometimes three months before they disappear, at which time they are generally converted into spots exceeding the rest of the sun in brightness. The general opinion concerning their nature is, that they are volcanoes, or burning mountains, of immense size; and that when the eruption is nearly ended, and the smoke dissipated, the fierce flames are exposed, and appear as luminous spots. Dr. Wilson supposes them, on the other hand, to be excavations in the luminous matter (or atmosphere) that environs the body of the sun.

“ The observations which might with fullness of evidence confirm the opinion of planetary worlds,

worlds, seem to be placed out of our reach, and we can scarce hope to make our optical instruments sufficiently perfect, to render the inhabitants thereof visible to us. All, therefore, that we can do, is to examine if the planets are accommodated with those things which we are used to consider as necessary to animal existence. Lands, seas, clouds, vapours, and an atmosphere, or body of air, are objects that we may expect to find on the face of an habitable world."

The moon being so very near us, and likewise in the same temperature as to light and heat, first presents itself. When we look at her with the naked eye, we discern a great number of irregular spots on her disk, distinguished by their dark colour from the brighter or more glaring parts; but when viewed through a telescope, their number is prodigiously increased; and it is perceived, that many of these appearances are occasioned by vast obscure pits or cavities, and elevations or mountains.

These mountains and cavities are known to be such, from the shadow they cast. In the first and second quarters, when the light of the sun falls obliquely upon them, the elevated parts cast a triangular shadow on the side opposite to the sun;

whereas, with respect to the cavities, these have that side which is opposite to the sun illuminated, and that which is next the sun is dark and obscure, the same as would happen to a hollow basin, placed on a table at some distance from a candle, in a room where there is no other light. The shadows shorten as the sun becomes more directly opposed to the anterior face of the moon, and at length disappear at the time of the full. During the third and last quarters, the shadows appear again, but all fall towards the contrary side of the moon, though still with the same distinction, namely, that the mountains are dark and shady on the side farthest from the sun, and the pits are dark on the side next the sun.

The full moon is a very pleasing sight through a telescope, and has a great variety of lustre and colour; but it is not the face on which to discover the mountains, these are best seen at the increase or decrease; for besides the evidence derived from the shadows, we may then see the tops of these mountains catching the rays of the sun before they reach that part of the surface on which their bottoms are placed.

On April 19, 1787, Dr. Herschel observed some appearance on the surface of the moon, which,
judging

judging by analogy from things perceived here with us, he thought he might term volcanoes. Three of these he observed in different places of the dark part of the moon; two of them appeared nearly extinct, or going to break out; the third, as an actual eruption of fire, or luminous matter. On the 20th it burnt with greater violence, and might be computed to be about three miles in diameter; the eruption resembled a piece of burning charcoal, covered by a thin coat of white ashes; all the adjacent parts of the volcanic mountain were faintly illuminated by the eruption, and were gradually more obscure as they lay at a greater distance from the crater. Dr. Herschel had, in 1783, observed an eruption, somewhat similar to that of the foregoing volcano.

That the moon is surrounded by an atmosphere, is rendered probable by many observations of solar eclipses, in which the edge or limb of the sun was observed to tremble just before the beginning. The planets are likewise observed to change their figure from round to oval, just before the beginning of an occultation behind the moon, which can be attributed to no other cause than that their light is refracted by being seen through the moon's atmosphere. That we see no clouds, will

not appear surprizing, if we consider that the lunar days and nights are thirty times as long as our's; it will be easy to conceive, that with them the phænomena of vapours may be very different from what they are with us; perhaps their clouds and rain, if any, may be condensed into visible quantities only during the absence of the sun, and of course when they must be invisible to us.

Mercury being at all times near the sun, we can only distinguish by the telescope a variation of his figure, which is sometimes that of a half moon, sometimes a little more or less than half.

Venus, when in the form of a crescent, and at her brightest times, affords a more pleasing telescopic view than any other of the heavenly bodies; her surface is diversified with spots, like those of the moon; by the motion of these, the time she takes up in revolving upon her axis is discovered. With a powerful telescope, mountains, like those in the moon, may be seen.

Mars appears always round and full, except at the time of the quadrature, when it's disk appears like that of the moon about three days after the full. By the spots which are seen on it's surface, it's diurnal revolution has been ascertained.

From

From it's characteristic ruddiness, and from other phænomena, it has been supposed that it's atmosphere is nearly of the same density with our's. Dr. Herschel has observed two white luminous circles surrounding the poles of this planet; these are supposed to arise from the snow lying about those parts.

The appearance of Jupiter through a telescope, opens a vast field for speculative inquiry. The surface is not equally bright, but is distinguished by certain bands, or belts, of a duskier colour than the rest of the surface, running parallel to each other, and to the plane of it's orbit. They are not regular or constant in their appearance; sometimes only one is seen, at other times eight have been seen; sometimes one or more spots are formed between the belts, which increase till the whole is united in one large dusky band. There are also bright spots to be discovered on Jupiter's surface; these are rather more permanent than the belts, and re-appear after unequal intervals of time. The remarkable spot, by whose motion the rotation of Jupiter on his axis was ascertained, disappeared in 1694, and was not seen again till 1708, when it re-appeared exactly in the same place, and has been occasionally seen ever since. The disappearance and re-appearing

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of

of the spots is not so wonderful as the changes that have been observed in the belts; the elder Cassini saw one evening five belts upon the planet, but while he was viewing them, they underwent the most surprizing change. In an hour from their fullest appearance there remained only three out of five, and one of these scarce perceptible.

Though the great distance of the planet Saturn, and the tenuity of it's light, do not permit us to distinguish the varieties of it's surface; yet some of the first discoveries made by the telescope were on this planet, and the ring is still one of the most curious phænomena we are acquainted with. There is not, indeed, any thing in the whole system of nature more wonderful than this ring, which appears nearly as bright as any part of the surface of the planet; by what means it is suspended, or by what law supported; whether it is only a bright but permanent cloud, or whether it is a vast number of satellites disposed in the same plane, whose blended light gives it to us the form of one continual body, we can only form crude conjecture. M. Messier has observed on the anles of this ring, several luminous white twinkling points, differing in vivacity from each other.

OF COMETS.

Comets are a kind of stars, appearing at unexpected times in the heavens, and of singular and various figures, descending from far distant parts of the system, with great rapidity, surprizing us with the singular appearance of a train, or tail; and after a short stay, are carried off to distant regions, and disappear.

They were imagined in ancient times to be prodigies hung out by the immediate hand of God in the heavens, and intended to alarm the world. Their nature being now better understood, they are no longer terrible. But as there are still many who think them to be heavenly warnings, portents of future events, it may not be improper for the tutor to inform his pupil, that the Architect of the universe has framed every part according to divine order, and subjected all things to laws and regulations: that he does not hurl at random stars and worlds, and disorder the system of the whole glorious frame, to produce false apprehensions of distant events, fears without foundation, and without use. Religion glories in the test of reason, of knowledge, and of true wisdom; it is every way connected with, and is always elucidated by them. From

2 philosophy

philosophy we may learn, that the more the works of the Lord are understood, the more he must be adored; and that his superintendency over every portion is more clearly evinced, and more fully expressed by their unvaried course, than by ten thousand deviations.

The existence of an universal connection between all the parts of nature is now generally allowed. Comets undoubtedly form a part of this great chain; but of the part they occupy, and of the uses for which they exist, we are equally ignorant. It is a portion of science whose perfection is reserved for some distant day, when these bodies and their vast orbits may, by long and accurate observation, be added to the known parts of the solar system.

The astronomy of comets is very imperfect; for but little can be known with certainty, where but little can be seen. Comets afford few observations on which to ground conjecture, and are for the greatest part of their course beyond the reach of human vision.

It is, however, now generally supposed, that they are planetary bodies, making part of our system, revolving round the sun in extremely long elliptic

elliptic curves. That as the orbit of a comet is more or less excentric, the distance to which they recede from the sun will be greater or less. Very great difference has been found by observation in this respect, even so great, that the sides of the elliptic orbit in some cases degenerate almost into right lines.

That those comets which go to the greatest distance from the sun, approach the nearest to him at their return.

Their motions in the heavens are not all direct, or according to the order of the signs, like those of the other planets. The number of those which move in a retrograde manner, is nearly equal to those whose motion is direct.

The orbits of most of them are inclined in very large angles to the plane of the ecliptic.

The velocity with which they move is variable in every part of their orbit; when they are near the sun, they move with incredible swiftness; when very remote from him, their motion is inconceivably slow.

They

They differ also in form from the other planets, consisting of a large internal body, which shines with the reflected light of the sun, and is encompassed with a very large atmosphere, apparently of a fine matter, replete with clouds and vapours; this is called the head of the comet, and the internal part the nucleus. When a comet arrives at a certain distance from the sun, an exhalation arises from it, which is called the tail.

The tail is always directed to that part of the heavens which is directly or nearly opposite to the sun, and is greater after the comet has past it's perihelium, than in it's approach to it, being greatest of all when it has just past the perihelium.

No satisfactory knowledge has been acquired concerning the cause of that train of light which accompanies the comets. Some philosophers imagine that it is the rarer atmosphere of the comet impelled by the sun's rays. Others, that it is the atmosphere of the comet, rising in the solar atmosphere by it's specific levity; while others imagine that it is a phænomenon of the same kind with the aurora borealis; and that this earth would appear like a comet to a spectator placed in another planet.

The number of the comets is certainly very great, considerably beyond any estimation that might be made from the observations we now possess.

OF A PLURALITY OF WORLDS.

The fixed stars are generally supposed to be of the same nature with our sun, each of them attended by planets, which are inhabited by rational creatures like this earth.

Instead, therefore, of one sun, and one world, we find that the region of unbounded space is peopled with suns, and stars, and worlds. This opinion has been held and taught by many of the most celebrated philosophers and astronomers, both in ancient and modern times: in this view of things, our system resembles a single individual of some one species of being in outward nature, diversified from all it's fellow individuals, by differences unessential to the kind and species; but which constitute that beauty, which arises from uniformity amidst variety.

That the fixed stars are suns, shining by their own light, is probable, on account of their immense distance from us; for as it is impossible
that

that at these distances they could be seen by any reflection of light from the sun, it is natural to suppose them endowed with a power of emitting light from their own bodies. By comparing the apparent diameter of objects at different distances, it is clear that our sun would appear like a star, were he removed to the distance at which they are placed ; and that therefore it is truly reasonable to suppose, that the fixed stars are equal, if not superior in magnitude to that which is the center of our system ; and that they are made for the same purposes with the sun, to bestow light, heat, and vegetation, on a certain number of planets revolving round them.

Of their immense distance from us, and the vastness of the space they occupy, the reader may form some idea, when he is told, that numbers amongst them are at too great a distance to be adequately expressed by figures; and beyond the reach of admeasurement ; and this will be heightened, if he considers that the smallest of the stars visible to the eye are much more remote than the larger ones, and that the telescope discovers stars which are too distant to be perceptible to the naked eye. That the instrument, like our eyes, has it's limits ; but the extent of the heavens has no bounds.

The fixed stars being so far removed from, and for the most part invisible to us, it can scarcely be conceived by the narrowest mind, that they form a part of our system, or were created only to give a faint glimmering light to the inhabitants of this globe; for one additional moon would have afforded us more light than the whole host of stars; such an opinion is unworthy of our reason, inadequate to our conceptions of the Deity. It would be also absurd to suppose that the author of nature had made so many suns without planets, to be enlightened by their light, and vivified by their heat; but more so, to imagine so many habitable worlds enlightened by suns without inhabitants; we may, therefore, safely conclude, that all the planets, of every system, are inhabited.

This reasoning is still further strengthened, by considering the immensity of the starry heavens, in which are innumerable hosts of stars, created as the means to some great end. From revelation we learn, that the ultimate end of creation is the peopling of heaven with men. These resplendent suns are clearly then the mediums of existence to so many earths, and of men upon them, created to be happy eternally with their God, "THE ONE ETERNAL THIRST TO BLESS."

"Every

“ Every star is thus the center of a magnificent system, attended by a retinue of worlds, irradiated by it's beams, and revolving round by it's active influence.” Thus the greatness of God is magnified, and the grandeur of his empire made manifest. He is not glorified on one earth, or in one world, but in ten thousand times ten thousand. “ If we could wing our way to the highest apparent star, we should there see other skies expanded, other suns that distribute their inexhaustible beams of day ; other stars, that gild the alternate night, and other (perhaps nobler) systems established in unknown profusion, through the boundless dimensions of space. Nor does the dominion of the Sovereign of all things terminate here ; even at the end of this vast tour we should find ourselves advanced no further than the frontiers of creation, the commencement of the great JEHOVAH's kingdom.”

This mode of reasoning applies with greater force to the planets of our own system, and gains additional strength from other considerations. For who would venture to assert, that infinite love and consummate wisdom had formed such immense material masses, some of which exceed our earth in size, convey them in revolutions round the sun, furnish them with moons, grant them

them the alternate changes of night and day, vicissitudes of seasons, and all this only to emit their scanty light on our earth.

Or who that has seen any engine, a windmill for instance, and who knows the use of it, if he travels into another country, and there sees an engine of the same sort, will not reasonably conclude that it is designed for the same purpose? So when we know that the use of this planet, the earth, is for an habitation of various sorts of animals, and we see other planets at a distance from us, some bigger, some less than the earth, moving periodically round, revolving on their axes, and attended with moons; is it not highly reasonable to conclude, that they are all designed for the same use as this earth is, and that they are habitable worlds like that we live in.

“ Who can conceive them

————— unpossess’d

By living foul, desert and desolate,

Only to shine, yet scarce to contribute

Each orb a gleam of light ?”

Or that the ALMIGHTY, who has not left with us a drop of water unpeopled, who has in every instance multiplied the bound of life, should leave

such immense bodies destitute of inhabitants? It is surely much more rational to suppose them the possession of human beings, beings formed with capacities for knowing, loving, and serving their Almighty Creator; blest and provided with every object conducive to their happiness, and many of them in a far greater state of purity than the inhabitants of our earth, and therefore in possession of higher degrees of bliss, and placed in situations, furnishing them with scenes of joy, equal to all that poetry can paint, or religion promise: all under the direction, indulgence, and protection of infinite wisdom and goodness.

A COMPREHENSIVE SURVEY OF THE UNIVERSE.

As this work is principally intended for young minds, the following view of the universe, by the amiable philosopher of Geneva, Mr. Bonnet, cannot but prove acceptable to the reader, not only because it will serve as a recapitulation of what has gone before, but as it will tend to enlarge his ideas, and increase his veneration for the Father of all beings.

When the shades of night have spread their veil over the azure plains, the firmament manifests to our view it's grandeur and it's riches.

The

The sparkling points with which it is sown, are so many SUNS suspended by the ALMIGHTY in the immensity of space; to give light and heat to the worlds which roll around them.

THE HEAVENS DECLARE THE GLORY OF GOD; AND THE FIRMAMENT SHEWETH HIS HANDY WORK. The royal poet, who expressed himself with such loftiness of sentiment, was ignorant that the stars he contemplated were in reality suns. He anticipated the times, and first sung that majestic hymn, which future and more enlightened ages should chaunt forth in praise to the FOUNDER OF WORLDS.

The assemblage of these vast bodies is divided into different systems, the number of which probably surpasses the grains of sand which the sea casts on it's shores.

Each system has at it's center, or focus, a star, or sun, which shines by it's native inherent light; and round which, several orders of opaque globes revolve, reflecting, with more or less brilliancy, the light they borrow from it, and which renders them visible.

Those globes which we perceive as wandering among the heavenly host, are the PLANETS; the primary, or principal ones, have the sun for the common center of their periodical revolution; while the others, which are called secondaries, move round their primaries, accompanying them as SATELLITES in their annual revolution.

The earth has one fatellite, Jupiter four, Saturn five, and the Georgium Sidus two; Saturn has besides a luminous and beautiful ring.

We know that our solar system consists of twenty planetary bodies; we are not certain but that there may be more. Their number has been considerably augmented since the invention of telescopes: more perfect instruments, and more accurate observers, may further increase their number; the discovery of the Georgium Sidus may be looked upon as the happy preface of future success.

Modern astronomy has not only enriched our heavens with new planets, but it has also enlarged the boundaries of the solar system. The comets, which from their fallacious appearance, their tail, their beard, the diversity of their directions, their sudden appearance and disappearance, have
been

been considered as meteors, lighted up in the air by an irritated power, are found to be a species of planetary bodies, whose long routes are now calculated by astronomers; they also foretel their distant return, determine their place, and account for their irregularities. Many of these bodies at present acknowledge the empire of our sun, though the orbits they trace round him are so extensive, that many ages are necessary for the completion of a revolution.

In a word, it is from modern astronomy that we learn that the stars are innumerable, and that the constellations, in which the ancients reckoned but a few, are now known to contain thousands. The heavens of Thales and Hipparchus were very poor when compared to those of Tycho Brahe, Flamsteed, de La Caille, and Herschel.

The diameter of the great orbit which our earth describes, is more than many millions of leagues; yet this vast extent vanishes into nothing, and becomes a mere point, when the astronomer wishes to use it as a measure, to ascertain the distance of the fixed stars.

How great then is the real bulk of these luminaries, which are perceptible by us at such

an enormous distance! the sun is about 1,392,500 times greater than the earth, and $539\frac{1}{2}$ times greater than all the planets taken together. If the stars are suns, as we have every reason to suppose, they must either be equal to, or exceed it in size.

Proud and ignorant mortal! lift up now thine eyes to heaven, and answer me: if one of those luminaries which adorn the starry heaven, should be taken away, would thy nights become darker? Say not then, that the stars are made for thee; that it is for thee that the firmament glitters with effulgent brightness: feeble mortal! thou wert not the chief object of the liberal bounties of the Creator, when he appointed Sirius, and encompassed it with worlds.

Whilst the planets perform their periodical revolutions round the sun, by which the course of their year is regulated, they turn round upon their axes, a motion by which they obtain the alternate succession of day and night.

But by what means are these vast bodies suspended in the immensity of space? What secret power retains them in their orbits, and enables them to circulate with so much regularity and harmony?

harmony? GRAVITY, or ATTRACTION, is the powerful agent, the universal principle of this equilibrium, and of these motions. It penetrates intimately all bodies. By this power, they tend toward each other in a proportion relative to their bulk. Thus the planets tend towards the center of the system, into which they would soon have been precipitated, if the Creator, when he formed them, had not impressed upon them a projectile or centrifugal force, which continually keeps them at a proper distance from the center.

The planets, by obeying at the same instant each of these motions, are made to describe a curve. This curve is an ellipse, of different excentricities, according to the combination of the active powers. At one of the foci of this ellipse the sun is placed. Thus the same force which determines the fall of a stone, is the ruling principle of the heavenly motions. Wonderful mechanism! whose simplicity and energy gives us unceasing tokens of the PROFOUND WISDOM OF ITS AUTHOR.

The earth, which seems so vast in the eyes of the emmets who inhabit it, and whose diameter is above 7970 miles, is yet near a thousand times

smaller than Jupiter, who appears to the naked eye as little more than a shining atom.

Two troops of academicians, new Argonauts, have had within this century the glory of determining the figure of the earth, and have demonstrated it to be a spheroid, flattened at the poles, elevated at the equator. But Newton has acquired a still greater glory, that of discovering, by the powers of genius, the same truth previous to observation. This figure is also the effect of gravity, combined with the centrifugal force. These two powers acting in different proportions, on different planets, vary their figure, and change them into spheroids, more or less flat, at the same time that they contract or dilate their orbits.

This terraqueous globe is externally divided by land and seas. It is internally formed (at least to a certain depth) into beds of heterogeneous matter; the beds are almost parallel, but of different densities and textures.

The surface of the earth abounds with irregularities. In one part we find vast plains, intersected with hills and vallies. In another, long chains of mountains, which lift their frozen heads

to the clouds ; from the bosom of these mountains proceed rivers, which, after they have watered various countries, and produced ponds and lakes, discharge themselves into the sea, and restore to it what it had lost by evaporation.

The sea presents to our view islands scattered in all parts of it, sands, rocks, currents, gulphs, and storms ; but above all, that regular and admirable motion whereby it's waters rise and fall twice every twenty-four hours.

The lands and seas are peopled with plants and animals, whose infinitely varied species have each their proper habitation. Mankind divided into nations, people, and families, cover the surface of the globe. They modify and enrich it by their various labours, and build dwellings from pole to pole, which correspond with their manners, genius, and climate.

A rare transparent and elastic substance surrounds the earth to a certain height. This substance is the atmosphere, the habitation of the winds, an immense reservoir of vapours, which, when condensed into clouds, either embellish our sky by the variety of their figures, and the richness of their colouring ; or astonish us
by

by the rolling thunder, or flashes of lightning, that escape from them; sometimes they melt away, at others are condensed into rain or hail, supplying the deficiencies of the earth with the superfluity of heaven.

The moon, the nearest of all the planets to the earth, is likewise that of which we have the most knowledge. It's globe always presents to us the same face, because it turns round upon it's axis precisely in the same space of time that it revolves round the earth.

It has it's phases, or gradual and periodical increase and decrease of light, according to it's position with respect to the sun, which enlightens it, and the earth on which it reflects the light that it has received.

The disk of the moon is divided into luminous and obscure parts. The former seems analogous to land, the latter to resemble our seas.

In the luminous spots there have been observed some parts which are brighter than the rest; these project a shadow, whose length has been measured, and their track ascertained. These parts are mountains, much higher than our's, in
6 proportion

proportion to the size of the moon, whose tops may be seen gilded by the rays of the sun, at the quadratures of the moon, and the light gradually descending to their feet, till they appear entirely bright. Some of these mountains stand by themselves, while in other places there are long chains of them.

We shall not dwell upon the numerous particulars that may be observed on an attentive examination of this planet. If the author of nature has with us thought proper to vary the smallest individual, how great must the diversity be, by which he has distinguished one world from another.

Venus has, like the moon, her phases, spots, and mountains. The telescope discovers to us also spots in Mars and Jupiter. Those in Jupiter form belts; considerable changes have been seen among these, as if of the ocean's overflowing the land, and again leaving it dry by it's retreat.

Mercury, Saturn, and the Georgium Sidus, are but little known; the first, because he is too near the sun; the two last, because they are so remote from it.

Lastly,

Laſtly, the ſun himſelf has ſpots, which ſeem to move with regularity, and whoſe ſize equals, and very often exceeds, our globe itſelf.

Every thing in the univerſe is ſyſtematical, all is combination, affinity, and connection.

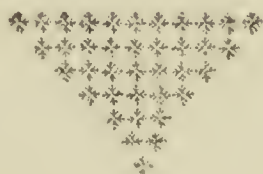
The ſpecies and individuals have relation to the ſize of the earth ; the ſize of the earth has it's relation to the place ſhe occupies in the planetary ſyſtem.

The ſun gravitates on the planets, the planets on the ſun and each other. Theſe taken together gravitate on their neighbouring ſyſtems, theſe again on more diſtant ones ; while the ballance of the univerſe remains in equilibrio, in the hands of the ANCIENT OF DAYS.

From the relations which exiſt between all parts of the world, and by which they conſpire to one general end, reſults the harmony of the world.

The relations which unite all the worlds to one another, conſtitute the harmony of the univerſe.

The beauty of the world is founded in the harmonious diversity of the beings that compose it, in the number, the extent, and the quality of their effects, and in the sum of happiness that arises therefrom.



E S S A Y I I.

P A R T I.

E S S A Y II.

P A R T I.

A TREATISE ON THE USE OF THE
TERRESTRIAL AND CELESTIAL GLOBES.

OF THE ADVANTAGES OF GLOBES IN GENERAL,
FOR ILLUSTRATING THE PRIMARY PRINCIPLES OF ASTRONOMY AND GEOGRAPHY; AND
PARTICULARLY OF THE ADVANTAGES OF THE
GLOBES, WHEN MOUNTED IN MY FATHER'S
MANNER.

UNIVERSAL approbation, the opinion of those that excel in science, and the experience of those that are learning, all concur to prove that the artificial representations of the earth and heavens, on the terrestrial and celestial globes, are the instruments the best adapted to convey natural and genuine ideas of astronomy and geography to young minds.

This superiority they derive principally from their form and figure, which communicates a

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more

more juſt idea, and a more adequate representation of the earth and heavens, than can be formed from any other figure.

To underſtand the nature of the projection of either ſphere in plano, requires more knowledge of geometry than is generally poſſeſſed by beginners, it's principles are more reclude, and the ſolution of problems by them more obſcure.

The motion of the earth upon it's axis is one of the moſt important principles both in geography and aſtronomy; on it the greater part of the phænomena of the viſible world depend: there is no invention that can communicate ſo natural a representation of this motion, as that of a terreſtrial globe about it's axis. By a celeftial globe, the apparent motion of the heavens is alſo repreſented in a natural and ſatisfactory manner.

In order to convey clear ideas of the various diviſions of the earth, of the ſituation of different places, and to obtain an eaſier ſolution of problems in geography, it is neceſſary to conceive many imaginary circles to be delineated on it's ſurface, and to underſtand their relation to each other. Now on a globe theſe circles have their true form, their interſections and relative

positions are visible upon the most cursory inspection. But in projections of the sphere in plano, the form of these circles is varied, and their nature changed; they are consequently but ill adapted to convey to young minds the elementary principles of geography.

On a globe, the appearance of the land and water is perfectly natural and continuous, and fitted to convey accurate ideas, and leave permanent impressions on the most tender minds; whereas, in planispheres one-half of the globe is separated and disjoined from the other; and those parts which are contiguous on a globe, are here separated and thrown at a distance from each other. The celestial globe has the same superiority over projections of the heavens in plano.

The globe exhibits every thing in true proportion, both of figure and size; while on a planisphere the reverse may often be observed.

Presuming that these reasons sufficiently evince the great advantage of globes over either planispheres or maps, for obtaining the first principles of astronomical and geographical knowledge, I proceed to point out the pre-eminence of globes mounted in my father's manner, over the common,

mon, or rather the old and Ptolemaic mode of fitting them up.

The great and increasing sale of the best globes may be looked upon at least as a proof of approbation from numbers; to this I might also add, the encouragement they have received from the principal tutors of both our universities, the public sanction of the university of Leyden, the many editions of my father's treatise on their use, and it's translation into Dutch, &c. The recommendation of Mess. Arden, Walker,* Burton, &c. public lecturers in natural philosophy, might also be adduced; but leaving these considerations, I shall proceed to enumerate the reasons which give them, in my opinion, a decided preference over every other kind of mounting.

The earth, by it's diurnal revolution on it's axis, is carried round from west to east. To represent this real motion of the earth, and to solve problems agreeable thereto, it is necessary that the globe, in the solution of every problem, should be moved from WEST TO EAST; and for this purpose, that the divisions on the large brass circle

* An Easy Introduction to Geography, by Mr. Walker.

circle should be on that side which looks westward.* Now this is the case in my father's mode of mounting the globes, and the tutor can thereby explain with ease the rationale of any problem to his pupil. But in the common mode of mounting, the globe must be moved from east to west, according to the Ptolemaic system; and consequently, if the tutor endeavours to shew how things obtain in nature, he must make his pupil unlearn in a degree what he has taught him, and by abstraction reverse the method he has instructed him to use, a practice that we hope will not be adopted by many.

The celestial globe being intended to represent the apparent motion of the heavens, should be moved, when used, from east to west.

Of the phænomena to be explained by the terrestrial globe, the most material are those which relate to the changes in the seasons; all the problems connected with, or depending upon these phænomena, are explained in a clear, familiar, and natural manner, by the globe,

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when

* See the Rev. Mr. Hutchins's New Treatise on the Globes, p. 3; Adams's Treatise on the Globes.

when mounted in my father's mode ; for on rectifying it for any particular day of the month, it immediately exhibits to the pupil the exact situation of the globe of the earth for that day ; and while he is solving his problem, the reason and foundation of it presents itself to the eye and understanding.

The globe may also be placed with ease in the position of a right sphere, a circumstance exceedingly useful, and which the old construction of the globes did not admit of.

By the application of a moveable meridian, and an artificial horizon connected with it, it is easy to explain why the sun, although he be always in one and the same place, appears to the inhabitants of the earth at different altitudes, and in different azimuths, which cannot be so readily done with the common globes.

On the celestial globe there is a moveable circle of declination, with an artificial sun.

The brass wires placed under the globes, serve to distinguish, in a natural and satisfactory manner, twilight from total darkness, and the reason of the length of it's duration.

The

The next point wherein they materially differ from other globes, is in the hour circle ; now it must be confessed, that to every contrivance that has been used for this purpose there is some objection, and probably no mode can be hit upon that will be perfectly free from them. The method adopted by my father appears to me the least exceptionable, and to possess some advantages over every other method I am acquainted with. Agreeable to the opinion of the first astronomers, among others of M. de la Lande, he uses the equator for the hour circle, not only as the largest, but also as the most natural circle that could be employed for that purpose, and by which alone the solution of problems could be obtained with the greatest accuracy. As on the terrestrial globe, the longitude of different places is reckoned on this circle ; and on the celestial, the right ascension of the stars, &c. it familiarizes the young pupil with them, and their reduction to time. This method does not in the least impede the motion of the globe ; but while it affords an equal facility of elevating either the north or south pole, it prevents the pupil from placing them in a wrong position ; and it is also prevented by the horary wire from falling out of the frame.

Another circumstance peculiar to these globes, is the mode of fixing the compass. It is self-evident, that the tutor, who is willing to give correct ideas to his pupil, should always make him keep the globes with the north pole directed towards the north pole of the heavens, and that, both in the solution of problems, and the explanation of phænomena. By means of the compass, the terrestrial globe is made to supply the purpose of a tellurian, when such an instrument is not at hand. I cannot terminate this paragraph, without testifying my disapprobation of a mode of making the globe turn round upon a pin in the pillar on which it is supported: a mode, that while it can give but little relief to indolence, is less firm in it's construction, and tends to introduce much confusion in the mind of the pupil.

In order to prevent that confusion and perplexity which necessarily arises in a young mind, when names are made use of which do not properly characterize the subject, my father found it necessary, with Mr. Hutchins, to term that broad wooden circle which supports the globe, and on which the signs of the ecliptic and the days of the month are engraved, the BROAD PAPER CIRCLE, instead of horizon, by which it had been heretofore denominated. The propriety of this change will

will be evident to all those who consider that this circle in some cases represents that which divides light from darkness, in others the horizon, and sometimes the ecliptic. For similar reasons, he was induced to call the brazen circle, in which the globes are suspended, the **STRONG BRASS CIRCLE.**

In a word, many operations may be performed by these globes, which cannot be solved by those mounted in the common manner; while all that they can solve may be performed by these, and that with a greater degree of perspicuity; and many problems may be performed by these at one view, which on the other globes require successive operations.

But as notwithstanding their superiority, the difference in price may make some persons prefer the old construction, it may be proper to inform them, that they may have my father's, or Senex's globes mounted in the old manner, at the usual prices.

E S S A Y II.

P A R T II.

E S S A Y II.

P A R T II.

CONTAINING A DESCRIPTION OF THE GLOBES
MOUNTED IN THE BEST MANNER; TOGETHER
WITH SOME PRELIMINARY DEFINITIONS.

DEFINITIONS.

BEFORE we begin to describe the globes,
it will be proper to take some notice of the
properties of a circle, of which a globe may be
said to be constituted.

A LINE is generated by the motion of a point.

Let there be supposed two points, the one
moveable, the other fixed.

If the moveable point be made to move
directly toward the fixed point, it will generate
in it's motion a strait line.

If

If a moveable point be carried round a fixed point, keeping always the same distance from it, it will generate a CIRCLE, or some part of a circle, and the fixed point will be the CENTER of that circle.

All strait lines going from the center to the circumference of a circle, are equal.

Every strait line that passes through the center of a globe, and is terminated at both ends by it's surface, is called a DIAMETER,

The extremities of a diameter are it's poles.

If the circumference of a semicircle be turned round it's diameter, as on an axis, it will generate a globe, or sphere.

The center of the semicircle will be the center of the globe; and as all points of the generating semicircle are at an equal distance from it's center, so all the points of the surface of the generated sphere are at an equal distance from it's center,

DESCRIPTION OF THE GLOBES.

There are two artificial globes ; on the surface of one of them the heavens are delineated, this is called the CELESTIAL GLOBE. The other, on which the surface of the earth is described, is called the TERRESTRIAL GLOBE.

Fig. 2, plate XIV. represents the celestial ; fig. 1, plate XIV. the terrestrial globe, as mounted in my father's manner.

In using the celestial globe, we are to consider ourselves as at the CENTER.

In using the terrestrial globe, we are to suppose ourselves on some point of it's SURFACE.

The motion of the terrestrial globe represents the REAL motion of the earth.

The motion of the celestial globe represents the APPARENT motion of the heavens.

The motion therefore of the celestial globe is a motion from EAST TO WEST.

But

But the motion of the terrestrial globe is a motion from WEST TO EAST.

On the surface of each globe several circles are described, to every one of which may be applied what has been said of circles in page 254.

The center of some of these circles is the same with the center of the globe; these are, by way of distinction, called GREAT CIRCLES.

Of these great circles, some are graduated.

The graduated circles are divided into 360 degrees, or equal parts, 90 of which make a quarter of a circle, or a quadrant.

Those circles whose centers do not pass through the center of the globe, are called LESSER CIRCLES.

The globes are each of them suspended at the poles in a strong brass circle N Z Æ S, and turn therein upon two iron pins, which are the axis of the globe; they have each a thin brass semicircle N H S, moveable about these poles, with a small thin circle H sliding thereon; it is quadrated
each

each way, to 90 degrees from the equator to either pole.

On the terrestrial globe this semicircle is a **MOVEABLE MERIDIAN**. It's small sliding circle, which is divided into a few of the points of the mariner's compass, is called a **TERRESTRIAL** or **VISIBLE HORIZON**.

On the celestial globe, this semicircle is a **MOVEABLE CIRCLE OF DECLINATION**, and it's small brass circle an artificial sun, or planet.

Each globe has a brass wire circle **T W Y**, placed at the limits of the crepusculum, or twilight, which, together with the globe, is mounted in a wooden frame; the upper part **B C** is covered with a broad paper circle, whose plane divides the globe into two hemispheres, and the whole is supported by a neat pillar and claw, with a magnetic needle in a compass box marked **M**.

A DESCRIPTION OF THE CIRCLES DESCRIBED ON
THE BROAD PAPER CIRCLE B C ; TOGETHER
WITH A GENERAL ACCOUNT OF IT'S USES.

It contains four concentric circular spaces, the innermost of which is divided into 360 degrees, and numbered into four quadrants, beginning at the east and west points, and proceeding each way to 90 degrees at the north and south points ; these are the four cardinal points of the horizon. The second circular space contains, at equal distances, the thirty-two points of the mariner's compass. Another circular space is divided into twelve equal parts, representing the twelve signs of the zodiac ; these are again subdivided into 30 degrees each, between which are engraved their names and characters. This space is connected with a fourth, which contains the calendar of months and days, each day on the 18 inch globes being divided into four parts, expressing the four cardinal points of the day, according to the Julian reckoning ; by which means, the sun's place is very nearly obtained for the common years after biffextile, and the intercalary day is inserted without confusion.

In all positions of the celestial globe, this broad paper circle represents the plane of the horizon,
and

and distinguishes the visible from the invisible part of the heavens ; but in the terrestrial globe it is applied to three different uses,

1. To distinguish the points of the horizon ; in this case it represents the rational horizon of any place.
2. It is used to represent the circle of illumination, or that circle which separates day from night.
3. It occasionally represents the ecliptic.

OF THE STRONG BRASS CIRCLE NÆZS.

One side of this strong brass circle is graduated into four quadrants, each containing 90 degrees.

The numbers on two of these quadrants increase from the equator towards the poles ; the other two increase from the pole towards the equator.

Two of the quadrants are numbered from the equator, to shew the distance of any point on the globe from the equator. The other two are num-

bered from the poles, for the more ready setting the globe to the latitude of any place.

The strong brass circle of the celestial globe is called the meridian, because the center of the sun comes directly under it at noon.

But as there are other circles on the terrestrial globe, which are called meridians, we chuse to denominate this the **STRONG BRASS CIRCLE, OR MERIDIAN.**

The graduated side of the strong brass circle that belongs to the terrestrial globe, should face the **WEST.**

The graduated side of the strong brazen meridian of the celestial globe should face the **EAST.**

On the strong brass circle of the terrestrial globe, and at about $23\frac{1}{2}$ degrees on each side of the north pole, the days of each month are laid down according to the declination of the sun.

OF THE HORARY CIRCLES, AND THEIR INDICES.

When the globes are mounted in my father's manner, we use the equator as the hour circle; because

because it is not only the most natural, but also the largest circle that can be applied for that purpose.

To make this circle answer the purpose, a semicircular wire is placed over it, carrying two indices, one on the east, the other on the west side of the strong brass circle.

As the equator is divided into 360° , or 24 hours, the time of one entire revolution of the earth or heavens, the indices will shew in what space of time any part of such revolution is made among the hours which are graduated below the degrees of the equator on either globe.

As the motion of the terrestrial globe is from west to east, the horary numbers increase according to the direction of that motion; on the celestial globe they increase from the east to the west.

OF THE QUADRANT OF ALTITUDE, Z A.

It is a thin, narrow, flexible slip of brass, that will bend to the surface of the globe; it has a nut, with a fiducial line upon it, which may be readily applied to the divisions on the strong brass meridian of either globe. One edge of the quadrant

is divided into 90 degrees, and the divisions are continued to 18 degrees below the horizon.

OF SOME OF THE CIRCLES THAT ARE DESCRIBED UPON THE SURFACE OF EACH GLOBE.

We may suppose as many circles to be described on the surface of the earth as we please, and conceive them to be extended to the sphere of the heavens, marking thereon concentric circles. For as we are obliged, in order to distinguish one place from another, to appropriate names to them, so are we obliged to use different circles on the globes, to distinguish the parts, and their several relations to each other.

OF THE EQUATOR, OR EQUINOCTIAL.

It goes round the globe exactly in the middle, between the two poles, from which it always keeps at the same distance ; or in other words, it is every where 90 degrees distant from each pole, and is therefore a boundary, separating the northern from the southern hemisphere ; hence it is frequently called the line by sailors, and when they sail over it they are said to cross the line.

It is that circle in the heavens, in which the sun appears to move on those two days, the one in the spring, the other in the autumn, when the days and nights are of an equal length all over the world; and hence on the celestial globe it is generally called the EQUINOCTIAL.

It is graduated into 360 degrees. Upon the terrestrial globe the numbers increase from the meridian of London westward, and proceed quite round to 360. They are also numbered from the same meridian eastward, by an upper row of figures, to accommodate those who use the English tables of latitude and longitude.

On the celestial globe, the equatorial degrees are numbered from the first point of Aries eastward, to 360 degrees.

Under the degrees on either globe is graduated a circle of hours and minutes. On the celestial globe the hours increase eastward, from Aries to XII at Libra, where they begin again in the same direction, and proceed to XII at Aries. But on the terrestrial globe, the horary numbers increase by twice twelve hours westward from the meridian of London to the same again.

In turning the globe about, the equator keeps always under one point of the strong brass meridian, from which point the degrees on the said circle are numbered both ways.

OF THE ECLIPTIC.

The graduated circle, which crosses the equator obliquely, forming with it an angle of about $23\frac{1}{2}$ degrees, is called the ecliptic.

This circle is divided into 12 equal parts, each of which contains 30 degrees. The beginning of each of these 30 degrees is marked with the characters of the 12 signs of the zodiac.

The sun appears always in this circle; he advances therein every day, nearly a degree, and goes through it exactly in a year.

The points where this circle crosses the equator are called the EQUINOCTIAL POINTS. The one is at the beginning of Aries, the other at the beginning of Libra.

The commencement of Cancer and Capricorn are called the SOLSTITIAL POINTS.

The twelve signs, and their degrees, are laid down on the terrestrial globe; but upon the celestial globe, the days of each month are graduated just under the ecliptic.

The ecliptic belongs principally to the celestial globe.



E S S A Y II.

P A R T III.

E S S A Y II.

P A R T III.

THE USE OF THE TERRESTRIAL GLOBE,
MOUNTED IN THE BEST MANNER.

OF LONGITUDE AND LATITUDE, AND OF
TERRESTRIAL MERIDIANS.

MERIDIANS are circular lines, going over the earth's surface, from one pole to the other, and crossing the equator at right angles.

Whatever places these circular lines pass through, in going from pole to pole, they are the meridians of those places.

There are no places upon the surface of the earth, through which meridians may not be conceived to pass. Every place, therefore, is supposed to have a meridian line passing over it's zenith from north to south, and going through the poles of the world.

Thus

Thus the meridian of Paris is one meridian; the meridian of London is another. This variety of meridians is satisfactorily represented on the globe, by the moveable meridian, which may be set to every individual point of the equator, and put directly over any particular place.

Whensoever we move towards the east or west, we change our meridian; but we do not change our meridian if we move directly to the north or south.

The moveable meridian shews that the poles of the earth divide every meridian into two semicircles, one of which passes through the place whose meridian it is, the other through a point on the earth, opposite to that place.

Hence it is, that writers in geography and astronomy generally mean by the MERIDIAN of any place the SEMICIRCLE which passes through that place; these, therefore, may be called the geographical meridians.

All places lying under the same semicircle, are said to have the same meridian; and the semicircle opposite to it is called the opposite meridian,

ridian, or sometimes the opposite part of the meridian.

From the foregoing definitions, it is clear that the meridian of any place is immoveably fixed to that place, and is carried round along with it by the rotation of the globe.

When the meridian of any place is by the revolution of the earth brought to point at the sun, it is noon, or mid-day, at that place.

The plane of the meridian of any place may be imagined to be extended to the sphere of the fixed stars.

When, by the motion of the earth, the plane of a meridian comes to any point in the heavens, as the sun, moon, &c. that point, &c. is then said to come to the meridian. It is in this sense that we generally use the expression of the sun or stars coming to, or passing over the meridian.

The time which elapses between the noon of any one day in a given place, and the noon of the day following in the same place, is called a natural day.

All places which lie under the same meridian, have their noon, and every other hour of the natural day, at the same time. Thus when it is one in the afternoon at London, it is also one in the afternoon to every place under the meridian of London,

In order to ascertain the situation of any point, there must first be a settled part of the earth's surface, from which to measure; and as the point to be ascertained may lie in any part of the earth's surface, and as this surface is spherical, the place from whence we measure must be a circle. It would be necessary, however, to establish two such circles, one to know how far any place may be east or west of another, the second to know it's distance north or south of the given point, and thus determine it's precise situation.

Hence it has been customary for geographers to fix upon the meridian of some remarkable place, AS A FIRST MERIDIAN, OR STANDARD; and to reckon the distance of any place to the east or west, or it's longitude, by it's distance from the first meridian. On English globes this first meridian is made to pass through London,

THE LONGITUDE OF ANY PLACE is it's distance from the first meridian, measured by degrees on the equator.

To find the longitude of a place, is to find what degree on the equator the meridian of that place crosses.

All places that lie under the same meridian, are said to have the same longitude; all places that lie under different meridians, are said to have different longitudes; this difference may be east or west, and consequently the difference of longitude between any two places, is the distance of their meridians from each other measured on the equator.

Thus if the meridian of any place cuts the equator in a point, which is fifteen degrees east from that point, where the meridian of London cuts the equator, that place is said to differ from London in longitude 15 degrees eastward.

Upon the terrestrial globe there are 24 meridians, dividing the equator into 24 equal parts, which are the hour circles of the places through which they pass.

The distance of these meridians from each other is 15 degrees, or the 24th part of 360 degrees; thus 15 degrees is equal to one hour.

By the rotation of the earth, the plane of every meridian points at the sun, one hour after that meridian which is next to it eastward; and thus they successively point at the sun every hour, so that the plane of the 24 meridian semicircles being extended, pass through the sun in a natural day.

To illustrate this, suppose the plane of the strong brass meridian to coincide with the sun, bring London to this meridian, and then move the globe round, and you will find these 24 meridians successively pass under the strong brass meridian, at one hour's distance from each other; till in 24 hours the earth will return to the same situation, and the meridian of London will again coincide with the strong brass circle.

By passing the globe round, as in the foregoing article, it will be evident to the pupil, that if one of these meridians, 15 degrees east of London, comes to the strong brass meridian, or points at the sun one hour sooner than the meridian of London, a meridian that is 30 degrees east,
comes

comes two hours sooner, and so on; and consequently they will have noon, and every other hour, so much sooner than at London; while those, whose meridian is 15 degrees westward from London, will have noon, and every other hour of the day, one hour later than at London, and so on, in proportion to the difference of longitude. These definitions being well understood, the pupil will be prepared not only to solve, but see the rationale of the following problems.

P R O B L E M I.

To find the longitude of any place on the globe.

The reader will find no difficulty in solving this problem, if he recollects the definition we have given of the word longitude, namely, that it is the distance of any place from the first meridian measured on the equator. Therefore, either set the moveable meridian to the place, or bring the place under the strong brass meridian, and that degree of the equator, which is cut by either of these brazen meridians, is the longitude in degrees and minutes, or the hour and minute of it's longitude, expressed in time.

As the given place may lie either east or west of the first meridian, the longitude may be expressed accordingly.

It appears most natural to reckon the longitude always westward from the first meridian; but it is customary to reckon one half round the globe eastward, and the other half westward from the first meridian. To accommodate those who may prefer either of these plans, there are two sets of numbers on our globes: the numbers nearest the equator increase westward, from the meridian of London quite round the globe to 360° , over which another set of numbers is engraved, which increase the contrary way; by which means, the longitude may be reckoned upon the equator, either east or west.

Example. Bring Boston, in New England, to the graduated edge of either the strong brass, or of the moveable meridian, and you will find it's longitude in degrees to be $70\frac{1}{2}$, or 4 h. 42 min. in time; Rome $12\frac{1}{2}$ degrees east, or 50 min. in time; Charles-Town, North America, is 79 deg. 50 min. west.

PROBLEM II.

To find the difference of longitude between any two places.

If the pupil understands what is meant by the difference of longitude, the rule for the solution of this problem will naturally occur to his mind. Now the difference of longitude between any two places is the quantity of an angle (at the pole) made by the meridians of those places measured on the equator. To express this angle upon the globe, bring the moveable meridian to one of the places, and the other place under the strong brass circle, and the required angle is contained between these two meridians, the measure or quantity of which is to be counted on the equator.

Example. I find the longitude of Rome to be $12\frac{1}{2}$ east, that of Constantinople to be 29, the difference is $17\frac{1}{2}$ degrees. Again, I find Jerufalem has 35 deg. 25 min. east longitude from London; and Pekin, in China, 116 deg. 52 min. east longitude, the difference is 81 deg. 27 min.; that is, Pekin is 81 deg. 27 min. east longitude from Jerufalem; or Jerufalem is 81 deg. 27 min. west longitude from Pekin.

If one place is east, and the other west of the first meridian, either find the longitude of both places westward, by that set of numbers which increase westward from the meridian of London to 360 deg. and the difference between the number thus found is the answer to the question :—or,

Add the east and west longitudes, and the sum is the difference of longitude ; thus the longitude of Rome is 12 deg. 30 min. east, of Charles-Town 79 deg. 50 min. west ; their sum, 91 deg. 20 min. is the difference required.

It may be proper to observe here, that the difference in time is the same with the difference of longitude, consequently that some of the following problems are only particular cases of this problem, or readier modes of computing this difference.

P R O B L E M I I I .

To find all those places where it is noon, at any given hour of the day, in another place; or in other words, (which may conduct the reader to the rationale of it's solution) to find what places have the sun upon their meridian, at any given hour of the day, in another proposed place.

As the diurnal motion of the earth, here represented by the terrestrial globe, is from west to east, it is plain that all places which are to the east of any particular meridian, must necessarily pass by the sun, before a meridian which is to the west of them can arrive at it.

We shall, therefore, divide this problem into three cases.

1. When the given hour is at London.
2. When the given hour is in the morning, and any where but at London.
3. When the given hour is in the afternoon, but not at London.

1. WHEN THE GIVEN HOUR IS AT LONDON.

As the first meridian on our globes passes through London, bring the given hour to the east of London, if it be in the morning, to the strong brass meridian, and all those places which are under it will have noon at the given hour; but bring the given hour west of London, if it is in the afternoon.

Example. Let it be required to know in what places it is XII o'clock, when it is ten in the morning at London. Therefore, bring that Xth hour on the equator, which is to the eastward of London, under the strong brass meridian, and the places that are under it's graduated edge will have the sun upon their meridian when it is ten in the morning at London. Suppose the given hour at London to be three o'clock, then bring that hour on the equator which is westward of London, to the strong brass meridian, and those places which lie under it will be noon when it is three in the afternoon at London.

2. IF THE GIVEN HOUR BE IN THE AFTERNOON,
BUT NOT AT LONDON.

Bring

Bring the given place to the strong brass meridian, and set one of the hour indexes to that XII which is most elevated; then turn the globe from WEST to EAST, till the index points to the given hour, and the strong brass meridian will pass over those places which have noon at the given hour in the proposed place.

Let the hour proposed be IV o'clock in the afternoon, at Port-Royal, in Jamaica. Bring Port-Royal to the strong brass meridian, and set the hour index to the most elevated XII; turn the globe from west to east, until the horary index points to IV o'clock, and the strong brass meridian will pass over those places which have noon at the given hour in Jamaica;

3. IF THE GIVEN HOUR BE IN THE MORNING,
BUT NOT AT LONDON.

Bring the given place to the strong brass meridian; set the hour index to the uppermost XII, and turn the globe from EAST to WEST, until the hour index points to the given hour; then the required places are under the strong brass meridian. Let the given hour be 30 min. past V at Cape Pafaro, in the island of Sicily: bring Pafaro to the meridian, set the hour index

to the most elevated XII, then move the globe westward, till the hour index points to 30 min. past V, and the places under the strong brass meridian will have noon when it is 30 min. past V in the afternoon at Pafaro, in Sicily.

P R O B L E M IV.

When it is noon at any place, to find what hour of the day it is at any other place.

Rule. Bring the place at which it is noon, to the strong brass meridian, and set the hour index to the uppermost XII, and then turn the globe about till the other place comes under the strong brass meridian, and the hour index will shew upon the equator the required hour.

If to the eastward of the place where it is noon, the hour found will be in the afternoon ; if to the westward, it will be in the forenoon.

Thus when it is noon at London, it is 50 min. past XII at Rome ; 32 min. past VII in the evening at Canton, in China ; 15 min. past VII in the morning at Quebec, in Canada.

P R O B L E M V.

At any given hour in the place where you are, to find the hour at any place proposed; or in other words, the hour where you are being given, to tell what hour it is in any other part of the world.

Rule. Bring the proposed place under the strong brass meridian, set the hour index to the given time, then turn the globe, till the place where you are is under the brass meridian, and the horary index will point to the hour required.

Thus suppose we are at London at IX o'clock in the morning, what is the time at Canton, in China? Answer, 31 min. past IV in the afternoon. When it is IX in the evening at London, it is about 15 min. past IV in the afternoon at Quebec, in Canada.

O F L A T I T U D E.

We have already observed, that the equator divides the globe into two hemispheres, the northern and the southern.

The latitude of a place is it's distance from the equator towards the north or south pole, measured by degrees upon the meridian of the place.

All places, therefore, that lie under the equator, are said to have NO LATITUDE.

All other places upon the earth are said to be in north or south latitude, as they are situated on the north or south side of the equator; and the latitude of any place will be greater or less, according as it is further from, or nearer to the equator.

Lines which keep always at the same distance from each other, are called PARALLELS.

If a circle, or circular line, be conceived keeping at the same distance from the equator, it will be a parallel to the equator.

Circles of this kind are commonly drawn on the terrestrial, on both sides of the equator.

A circle of this kind at 10 degrees from the equator, is called a parallel of 10 degrees.

When

When any such parallel passes through two places on the globe's surface, those two places have the same latitude.

Hence parallels to the equator are called
PARALLELS OF LATITUDE.

There are four principal lesser circles parallel to the equator, which divide the globe into five unequal parts, called ZONES.

The circle on the north side of the equator is called the TROPIC OF CANCER; it just touches the north part of the ecliptic, and shews the path the sun appears to describe, the longest day in summer.

That which is on the south side of the equator, is called the TROPIC OF CAPRICORN; it just touches the south part of the ecliptic, and shews the path the sun appears to describe, the shortest day in winter.

The space between these two tropics, which contains about 47 degrees, was called by the ancients, the TORRID ZONE.

The two polar circles are placed at the same distance from the poles, that the two tropics are from the equator.

One of these is called the NORTHERN, the other the SOUTHERN POLAR CIRCLE.

These include $23\frac{1}{2}$ degrees on each side of their respective poles, and consequently contain 47 degrees, equal to the number of degrees included between the tropics.

The space contained within the northern polar circle, was by the ancients called the NORTH FRIGID ZONE; and that within the southern polar circle, the SOUTH FRIGID ZONE.

The spaces between either polar circle, and it's nearest tropic, which contain about 43 degrees each, were called by the ancients the TWO TEMPERATE ZONES.

P R O B L E M VI.

To find the latitude of any place.

If the pupil comprehends the foregoing definition, he will find no difficulty in the solution of this and some of the following problems.

Rule. Bring the place to the graduated side of the strong brass meridian, and the degree which is over it is it's latitude. Thus London will be found to have 51 deg. 32 min. north latitude; Constantinople 41 deg. north latitude; and the Cape of Good Hope 34 deg. south latitude.

P R O B L E M VII.

To find all those places which have the same latitude with any given place.

Suppose the given place to be London; turn the globe round, and all those places which pass under the same point of the strong brass meridian, are in the same latitude.

P R O B L E M VIII.

To find the difference of latitude between two places.

Rule. If the places be in the same hemisphere, bring each of them to the meridian, and subtract the latitude of one from the other. If they are in different hemispheres, add the latitude of one to that of the other.

Example. The latitude of London is 51 deg. 32 min.; that of Constantinople 41 deg.; their difference is 10 deg. 32 min. Of the difference between London, 51 deg. 32 min. north, and the Cape of Good Hope, 34 deg. south, is 84 deg. 32 min.

P R O B L E M IX.

The latitude and longitude of any place being known, to find that place upon the globe; or if the place be not inserted on the globe, to find where it ought to be placed, and fix the center of the artificial horizon thereto.

Rule. Seek for the given longitude in the equator, and bring the moveable meridian to that point;

point; then count from the equator on the meridian, the degree of latitude either towards the north or south pole, and bring the artificial horizon to that degree, and the intersection of it's edge with the meridian, is the situation required.

Example. The latitude of Smyrna, in Asia, is 38 deg. 28 min. north; it's longitude 27 deg. 30 min. east of London; therefore, bring 27 deg. 30 min. counted eastward on the equator, to the moveable meridian, and slide the diameter of the artificial horizon to 38 deg. 28 min. north latitude, and it's center will be correctly placed over Smyrna.

It may be proper in this place just to shew the pupil, that THE LATITUDE OF ANY PLACE IS ALWAYS EQUAL TO THE ELEVATION OF THE POLE OF THE SAME PLACE ABOVE THE HORIZON. The reason of this is, that from the equator to the pole is 90 degrees, from the zenith to the horizon is also 90 degrees; the distance of the zenith to the pole is common to both, and therefore if taken away from both, must leave equal remains; that is, the distance from the equator to the zenith, which is the latitude, is equal to the elevation of the pole.

As the finding the longitude of places forms one of the most important problems in geography and astronomy, some further account of it, it is presumed, will prove entertaining and useful to the reader.

“ For what can be more interesting to a person in a long voyage, than to be able to tell upon what part of the globe he is, to know how far he has travelled, what distance he has to go, and how he must direct his course to arrive at the place he designs to visit ; these important particulars are all determined by knowing the latitude and longitude of the place under consideration. When the discovery of the compass invited the voyager to quit his native shore, and venture himself upon an unknown ocean, that knowledge which before he deemed of no importance, now became a matter of absolute necessity. Floating in a frail vessel, upon an uncertain abyss, he has consigned himself to the mercy of the winds and waves, and knows not where he is.” *

† The following instance will prove of what use it is to know the longitude of places at sea. The editor of Lord Anson’s voyage, speaking of the island

island of Juan Fernández, adds, "The uncertainty we were in of it's position, and our standing in for the main on the 28th of May, in order to secure a sufficient casting, when we were indeed extremely near it, cost us the lives of between 70 and 80 of our men, by our longer continuance at sea ; from which fatal accident, we might have been exempted, had we been furnished with such an account of it's situation, as we could fully have depended on."

The latitude of a place the sailor can easily discover ; but the longitude is a subject of the utmost difficulty, for the discovery of which many methods have been devised. It is indeed of so great consequence, that the parliament of Great Britain proposed a reward of 10,000 *l.* if it extended only to 1 degree of a great circle, or 60 geographical miles ; 15,000 *l.* if found to 40 such miles ; and 20,000 *l.* to the person that can find it within 30 minutes of a great circle, or 30 geographical miles.

We cannot enter fully into this subject in these essays ; it will, I hope, be deemed sufficient, if we give such an account as will enable the reader to form a general idea of the solution of this important problem.

From what has been seen in the preceding pages, it is evident that 15 degrees in longitude answer to one hour in time, and consequently that the longitude of any place would be known, if we knew their difference in time; or in other words, how much sooner the sun, &c. arrives at the meridian of one place, than that of another. The hours and degrees being in this respect commensurate, it is as proper to express the distance of any place in time, as in degrees.

Now it is clear, that this difference in time would be easily ascertained by the observation of any instantaneous appearance in the heavens, at two distant places; for the difference in time at which the same phænomenon is observed, will be the distance of the two places from each other in longitude; on this principle, most of the methods in general use are founded.

Thus if a clock, or watch, was so contrived, as to go uniformly in all seasons, and in all places; such a watch being regulated to London time, would always shew the time of the day at London; then the time of the day under any other meridian being found, the difference between that time, and the corresponding London time, would give the difference in longitude.

For

For supposing any person possessed of one of these time-pieces, to set out on a journey from London, if his time-piece be accurately adjusted, wherever he is, he will always know the hour at London exactly; and when he has proceeded so far either eastward or westward, that a difference is perceived betwixt the hour shewn by his time-piece, and those of the clocks and watches at the places to which he goes, the distance of those places from London in longitude will be known. But to whatever degree of perfection such movements may be made, yet as every mechanical instrument is liable to be injured by various accidents, other methods are obliged to be used, as the eclipses of the sun and moon, or of Jupiter's satellites. Thus supposing the moment of the beginning of an eclipse was at ten o'clock at night at London, and by accounts from two observers in two other places, it appears that it began with one of them at nine o'clock, and with the other at midnight; it is plain, that the place where it began at nine is one hour, or 15 degrees east in longitude from London; the other place where it began at midnight, is 30 degrees distant in west longitude from London. Eclipses of the sun and moon do not, however, happen often enough to answer the purposes of navigation;

and the motion of a ship at sea prevents the observations of those of Jupiter's satellites.

If the place of any celestial body be computed, for example, as in an almanack, for every day, or to parts of days, to any given meridian; and the place of this celestial body can be found by observation at sea, the difference of time between the time of observation and the computed time, will be the difference of longitude in time. The moon is found to be the most proper celestial object, and the observations of her appulses to any fixed star is reckoned one of the best methods for resolving this difficult problem.

LENGTH OF THE DEGREES OF LONGITUDE.

Supposing the earth to be a perfect globe, the length of a degree upon the meridian has been estimated to be 69,1 miles; but as the earth is an oblate spheroid, the length of a degree on the equator will be somewhat greater.

Whether the earth be considered as a spheroid or a globe, all the meridians intersect one another at the poles. Therefore, the number of miles in a degree must always decrease as you go north or south from the equator. This is evident by inspection

specification of a globe, where the parallels of latitude are found to be smaller in proportion as they are nearer the pole.

The following TABLE shews how many geographical miles, and decimal parts of a mile, would be contained in a degree of longitude, at each degree of latitude from the equator to the poles, if the earth was a perfect sphere, and the circumference of it's equinoctial line 360 degrees, and each degree 60 geographical miles.

This table enables us to determine the velocity with which places upon the globe revolve eastward; for the velocity is different, according to the distance of the places from the equator, being swiftest as passing through a greater space, and so by degrees slower towards the poles, as passing through a less space in the same time. Now as every part of the earth is moved through the space of it's circumference, or 360 degrees in 24 hours; the space described in one hour is found by dividing 360 by 24, which gives in the quotient 15 degrees; and so many degrees does every place on the earth move in an hour. The number of miles contained in so many degrees in any latitude, is readily found from the table.

Thus under the equator places revolve at the rate of more than 1000 miles in an hour; at London, at the rate of about 640 miles in an hour,

T A B L E.

LAT.		LAT.		LAT.	
<i>Deg.</i>	<i>Miles.</i>	<i>Deg.</i>	<i>Miles.</i>	<i>Deg.</i>	<i>Miles.</i>
00	60,00	31	51,43	62	28,17
1	59,99	32	50,88	63	27,24
2	59,96	33	50,32	64	26,30
3	59,92	34	49,74	65	25,36
4	59,86	35	49,15	66	24,41
5	59,77	36	48,54	67	23,45
6	59,67	37	47,92	68	22,48
7	59,56	38	47,28	69	21,50
8	59,42	39	46,62	70	20,52
9	59,26	40	45,95	71	19,54
10	59,08	41	45,28	72	18,55
11	58,89	42	44,59	73	17,54
12	58,68	43	43,88	74	16,53
13	58,46	44	43,16	75	15,52
14	58,22	45	42,43	76	14,51
15	57,95	46	41,68	77	13,50
16	57,67	47	40,92	78	12,47
17	57,37	48	40,15	79	11,45
18	57,06	49	39,36	80	10,42
19	56,73	50	38,57	81	9,38
20	56,38	51	37,76	82	8,35
21	56,01	52	36,94	83	7,32
22	55,63	53	36,11	84	6,28
23	55,23	54	35,26	85	5,23
24	54,81	55	34,41	86	4,18
25	54,38	56	33,55	87	3,14
26	53,93	57	32,68	88	2,09
27	53,46	58	31,79	89	1,05
28	52,97	59	30,90	90	0,00
29	52,47	60	30,00		
30	51,96	61	29,09		

Another

Another circumstance which arises from this difference of meridians in time, must detain us a little before we quit this subject. For from this difference it follows, that if a ship sails round the world, always directing her course eastward, she will at her return home find she has gained one whole day of those that stayed at home; that is, if they reckon it May 1, the ship's company will reckon it May 2; if westward, a day less, or April 30.

This circumstance has been taken notice of by navigators. "It was during our stay at Mindanao (says Capt. Dampier) that we were first made sensible of the change of time in the course of our voyage: for having travelled so far westward, keeping the same course with the sun, we consequently have gained something insensibly in the length of the particular days, but have lost in the tale the bulk or number of the days or hours.

"According to the different longitudes of England and Mindanao, this isle being about 210 degrees west from the Lizard, the difference of time at our arrival at Mindanao, ought to have been about fourteen hours; and so much we should have anticipated our reckoning, having gained it by bearing the sun company.

"Now

“ Now the natural day in every place must be consonant to itself; but going about with, or against the sun’s course, will of necessity make a difference in the calculation of the civil day, between any two places. Accordingly, at Mindanao, and other places in the East Indies, we found both natives and Europeans reckoning a day before us. For the Europeans coming eastward, by the Cape of Good Hope, in a course contrary to the sun and us, wherever we met, were a full day before us in their accounts.

“ So among the Indian Mahometans, their Friday was Thursday with us; though it was Friday also with those that came eastward from Europe.

“ Yet at the Ladrone islands we found the Spaniards of Guam keeping the same computation with ourselves; the reason of which I take to be, that they settled that colony by a course westward from Spain; the Spaniards going first to America, and thence to the Ladrone islands.”

It is clear, from what has been said in the first part of this article, concerning both latitude and longitude, that if a person travel ever so far directly towards east or west, his latitude would be
always

always the same, though his longitude would be continually changing.

But if he went directly north or south, his longitude would continue the same, but his latitude would be perpetually varying.

If he went obliquely, he would change both his latitude and longitude.

The longitude and latitude of places give only their relative distances on the globe ; to discover, therefore, their real distance, we have recourse to the following problem.

P R O B L E M X.

Any place being given, to find the distance of that place from another, in a great circle of the earth.

We shall divide this problem into three cases.

Case 1. If the places lie under the same meridian. Bring them up to the meridian, and mark the number of degrees intercepted between them. Multiply the number of degrees thus found by 60, and they will give the number of
geogra-

geographical miles between the two places. But if we would have the number of English miles, the degree before found must be multiplied by $69\frac{1}{2}$.

Case 2. If the places lie under the equator. Find their difference of longitude in degrees, and multiply as in the preceding case, by 60, or $69\frac{1}{2}$.

Case 3. If the places lie neither under the same meridian, nor under the equator. Then lay the quadrant of altitude over the two places, and mark the number of degrees intercepted between them. These degrees multiplied as above-mentioned, will give the required distance.

A PARALLEL SPHERE is that position of the globe, in which the poles are in their zenith and nadir, it's axis at right angles to the equator and horizon, which coincide; consequently, those circles which are parallel to the equator, are also parallel to the horizon.

The inhabitants that answer to this position of the sphere, if any there be, must live upon the two terrestrial poles, and will have but one day and one night throughout the year, each fix months

months long. The day, to those who live under the north pole, begins when the sun enters Aries, and continues till he reaches Libra, when night commences, and continues the other six months. Those who live under the south pole, experience the direct contrary ; but both enjoy a long continuance of twilight, after the sun has departed from them, and before he appears again.

For half a year, the inhabitants of the pole see the sun moving continually round above their horizon, in a kind of spiral line ; when they first perceive him, he skims, as it were, their horizon, then rises gradually higher, till he reaches the tropic, when he again descends, till he touches the horizon, when their long and gloomy night begins.

During their summer's day, the moon appears to them in the heavens only as a white cloud ; in the winter, during her second and third quarters, she circulates above the horizon for several days, without setting, being a fortnight above, and a fortnight below the horizon.

They can only see the stars in that hemisphere between the pole and the equator ; during half a year, none of them are visible, being swallowed
up,

up, as it were, by the superior light of the sun. To them the stars never set, but move in circles parallel to the horizon, keeping always the same altitude. The planets are half their time above, and half below the horizon.

A RIGHT SPHERE is that in which the equator is at right angles to the horizon, and therefore in the zenith and nadir, and in which the poles are in the horizon.

The inhabitants that answer to this situation of the sphere, live under the equator; their days and nights are of an equal length throughout the year, being each of them twelve hours in length.

The sun rises and sets nearly perpendicular; he is half a year on one side their zenith, and as much on the other, passing over it twice a year at the equinoxes.

There is nothing uncommon in the appearance of the moon, but her rising and setting like the sun, nearly in a perpendicular direction; but there is to these inhabitants a most glorious display of all the stars in the heavens, from pole to pole, all of them rising and setting perpendicular, except the poles which lie in the horizon.

AN OBLIQUE SPHERE is the position common to all the inhabitants of the earth, except those who live at the poles, and upon the equator; it is thus named, because the equator cuts the horizon obliquely.

In this sphere the axis of the earth always makes an acute angle with the horizon; the equator is half above and half below it.

All the parallels to the equator cut the horizon also obliquely, and thus make the diurnal arches greater or less than the nocturnal ones, excepting at the time of the equinoxes.

Those inhabitants of this sphere, who live without the tropics, never have the sun in their zenith; but under the tropics the sun is vertical once, and between the tropics and the equator twice every year.

In this position the stars rise and set obliquely; and as the moon, when at full, is always in an opposite sign to the sun, she is on the south side of the equator in summer, and consequently her altitude is low, and her course short; but in winter, when at the full, she is in the northern signs,

signs, making a high long circuit, which is of great use in that dreary season.

OF THE DIURNAL MOTION OF THE EARTH.

As the daily motion of the earth about it's axis, and the phænomena dependent on it, are some of the most essential points which a beginner ought to have in view, we shall now endeavour to explain it by the globes; and here, I think, the advantage of globes mounted in my father's manner, over those generally used, will be very evident.

We have already observed, that in globes mounted in our manner, the motion of the terrestrial globe about it's axis represents the diurnal motion of the earth, and that the horary index will point out upon the equator the 24 hours of one diurnal rotation, or any part of that time.

We shall now consider the broad paper circle as the plane which distinguishes light from darkness; that is, the enlightened half of the earth's surface, from that which is not enlightened.

For when the sun shines upon a globe, he shines only upon one half of it ; that is, one half of the globe's surface is enlightened by him, the other not.

That the enlightened half may be that half which is above the broad paper circle, we must imagine the sun to be in our ZENITH.

Or let a sun be painted on the ceiling over the terrestrial globe, the diameter of the picture equal to the diameter of the globe.

Then all those places that are above the broad paper circle, will be in the sun's light ; that is, it will be DAY in all those places.

And all places that are below this circle, will be out of the sun's light ; that is, in all those places it will be NIGHT.

When any place on the earth's surface comes to the edge of the broad paper circle, passing out of the shade into the light, the sun will appear RISING at that place.

And

And when a place is at the edge of the broad paper circle, going out of the light into the shade, the sun will appear at that place to be SETTING.

When we view the globe in this position, we at once see the situation of all places in the illuminated hemisphere, whose inhabitants enjoy the light of the day. One edge of the broad paper circle shews at what place the sun appears rising at the SAME time. And the opposite edge shews at what places the sun is setting at the same time.

The horary index shews how long a place is moving from one edge to the other ; that is, how long the day or night is at that place.

TO RECTIFY THE TERRESTRIAL GLOBE.

To rectify the terrestrial globe, is to place it in the same position in which our earth stands to the sun, at all or any given times.

That half of the earth's surface, which is enlightened by the sun, is not always the same ; it differs according as the sun's declination differs.

To rectify then the terrestrial globe, is to bring it into such a position, as that the enlightened half of the earth's surface may be all above the broad paper circle.

On the back side of the strong brass meridian, and on each side of the north pole, the months and days of the month, are graduated in two concentric spaces, agreeable to the declination of the sun.

Bring the day of the month that is graduated, on the back side of the strong brass meridian, to coincide with the broad paper circle, and the globe is rectified.

Thus set the first of May to coincide with the broad paper circle, and that half of the earth's surface which is enlightened at any time upon that day, will be all at once above the said circle.

If the horary index be set to XII when any particular place is brought under the strong brass meridian, it will shew the precise time of sun-rising and sun-setting at that place.

It will also shew how long any place is in moving from the east to the west side of the illuminated disc, and thence the length of the day and night.

It will also point out the length of the twilight, by shewing the time in which the place is passing from the twilight circle to the edge of the broad paper circle on the western side; or from the edge of this circle on the eastern side, to the twilight wire, and thus determine the length of the whole artificial day.

N. B. The twilight wire is placed at 18 degrees from the broad paper circle.

We shall now proceed to exemplify upon the globes these particulars, at three different seasons of the year, viz. the summer solstice, the winter solstice, and the time or times of the equinoxes.

P R O B L E M X I.

To place the globe in the same situation, with respect to the sun, as our earth is in at the time of the summer solstice.

Rectify the globe to the extremity of the divisions for the month of June, or $23\frac{1}{2}$ degrees north declination; that is, bring these divisions on the strong brass meridian to coincide with the plane of the broad paper circle.

Then that part of the earth's surface, which is within the northern polar circle, will be above the broad paper circle, and will be in the light, and the inhabitants thereof will have no night,

But all that space which is contained within the southern polar circle, will continue in the shade; that is, it will there be continual night.

In this position of the globe, the pupil will observe how much the diurnal arches of the parallels of latitude decrease, as they are more and more distant from the elevated pole.

If any place be brought under the strong brass meridian, and the horary index is set to that XII
which

which is most elevated, and the place be afterwards brought to the western side of the broad paper circle, the hour index will shew the time of sun-rising; and when the place is moved to the eastern edge, the index points to the time of sun-setting.

The length of the day is obtained by the time shewn by the horary index, while the globe moves from the west to the east side of the broad paper circle.

Thus it will be found, that at London the sun rises about 15 minutes before IV in the morning, and sets about 15 minutes after VIII at night.

At the following places, it will be nearly at the times expressed in the table.

	☉ Rising.	☉ Setting	Length of day.	Twilight.
	<i>h. m.</i>	<i>h. m.</i>	<i>h. m.</i>	<i>h. m.</i>
Cape Horn - -	8 44	3 16	6 32	2 35
Cape of Good Hope	7 9	4 51	9 42	1 43
Rio de Janeiro, in Brazil	6 42	5 19	10 38	1 23
Island of St. Thomas,				
near the equator -	6	6	12	1 20
Cape Lucas, California	5 12	6 48	13 36	1 35

We also see, that at the same time the sun is rising at London, it is rising at the isles of Sicily and Madagascar.

And, that at the time when the sun sets at London, it is setting at the island of Madeira, and at Cape Horn.

And when the sun is setting at the island of Borneo, in the East Indies, it is rising at Florida, in America, and many other similar circumstances relative to other places, are seen as it were by inspection.

P R O B L E M XII.

To explain the situation of the earth, with respect to the sun, at the time of the winter solstice.

Rectify the globe to the extremity of the divisions for the month of December, or to $23\frac{1}{2}$ degrees south declination.

When it will be apparent that the whole space within the southern polar circle is in the sun's light, and enjoys continual day; whilst that of the northern polar circle is in the shade, and has continual night.

If

If the globe be turned round, as before, the horary index will shew, that at the several places before-mentioned their days will be respectively equal to what their nights were at the time of the summer solstice,

It will appear farther, that it is now sun-setting at the same time in those places, in which it was sun-rising at the same time at the summer solstice. And on the contrary, sun-rising at the time it then appeared to set.

P R O B L E M XIII.

To place the globe in the situation of the earth, at the times of the equinox.

The sun has no declination at the times of the equinox, consequently there must be no elevation of the pole.

Bring the day of the month when the sun enters the first point of Aries, or day of the month when the sun enters the first point of Libra, to the plane of the broad paper circle; then the two poles of the globe will be in that plane also, and the globe will be in the position which is called a RIGHT SPHERE.

For

For it is a right sphere when the two poles are in the plane of the broad paper circle, because then all those circles which are parallel to the equator will be at right angles to that plane.

If the globe be now turned from west to east, it will plainly appear, that all places upon it's surface are twelve hours above the broad paper circle, and twelve hours below it; that is, the days are twelve hours long all over the earth, and that the nights are equal to the days, whence these times are called the times of equinox.

Two of these occur in every year; the first in the autumnal, the second the vernal equinox.

At these seasons the sun appears to rise at the same time to all places that are on the same meridian. The sun sets also at the same time in all those places.

Thus if London and Mundford, on the gold coast, be brought to the strong brass meridian, the graduated side of which is in this case the horary index, and they be afterwards carried to the western edge of the broad paper circle, the index will shew that the sun rises at VI at both places;

places ; when they are carried to the eastern edge, the index points to VI for the time of sun-setting.

N. B. If London be not the given place, the hour index is to be set to the most elevated XII, while the place is under the graduated edge of the strong brass meridian.

OF THE ARTIFICIAL, OR TERRESTRIAL HORIZON.

The brass circle, which may be slipped from pole to pole on the moveable meridian, has been already described, page 257. The circumference of it is divided into eight parts, to which are affixed the initial letters of the mariner's compass.

When the center of it is set to any particular place, the situation of any other place is seen, with respect to that place ; that is, whether they be east, west, north, or south of it.

It will, therefore, represent the horizon of that place.

We shall here use this artificial horizon, to shew why the sun, although he be always in one and the same place, appears to the inhabitants of
the

the earth at different altitudes, and in different azimuths.

P R O B L E M X I V .

To exemplify the sun's altitude, as observed with an artificial horizon.

The altitude of the sun is greater or less, according as the line which goes from us to the sun is nearer to, or farther off from our horizon.

Let the moveable circle be applied to any place, as London, then will the horizon of London be thereby represented.

The sun is supposed, as before, to be in the zenith, that is, directly over the terrestrial globe.

If then from London a line go vertically upwards, the sun will be seen at London in that line.

At sun-rising, when London is brought to the west edge of the broad paper circle, the supposed line will be parallel to the artificial horizon, and the sun will then be seen in the horizon.

As

As the globe is gradually turned from the west towards the east, the horizon will recede from that line which goes from London vertically upwards ; so that the line in which the sun is seen, gets further and further from the horizon, that is, the sun's altitude increases gradually.

When the horizon, and the line which goes from London vertically upwards, are arrived at the strong brass meridian, the sun is then at his greatest or meridian altitude for that day, and the line and horizon are at the largest angle they can make with each other.

After this, the motion of the globe being continued, the angle between the artificial horizon, and the line which goes from London vertically upwards, continually decreases, until London arrives at the eastern edge of the broad paper circle ; it's horizon then becomes vertical again, and parallel to the line which goes vertically upwards. The sun will again appear in the horizon, and will set.

P R O B L E M X V .

Of the sun's meridian altitude, at the three different seasons.

Rectify the globe to the time of the winter solstice, by problem xii. and place the center of the visible horizon on London.

When London is at the graduated edge of the strong brass meridian, the line which goes vertically upwards makes an angle of about 15 degrees ; this is the sun's meridian altitude at that season, to the inhabitants of London.

If the globe be rectified to the times of equinox, by problem xii. the horizon will be farther separated from the line which goes vertically upwards, and makes a greater angle therewith, it being about $38\frac{1}{2}$ degrees ; this is the sun's meridian altitude, at the time of equinox at London.

Again, rectify to the summer solstice by prob. xi. and you will find the artificial horizon recede farther from the line which goes from London vertically upwards, and the angle it then makes is about 62 degrees, which shews the sun's meridian altitude at the time of the summer solstice.

Hence

Again, to the elevation of the equator		
at London	—	38° 28
Add the sun's greatest declination at the		
time of the summer solstice	-	23 29
		<hr/>
The sum is the sun's greatest meridian		
altitude at London	—	61 57
		<hr/>

P R O B L E M XVII.

Of the sun's azimuths, as compared with the artificial horizon.

The artificial horizon serves also to determine the sun's azimuths.

An AZIMUTH of the sun is denominated from that point of the horizon, to which the sun, or a line going to the sun, is nearest.

Thus if the sun, or a line going to the sun, be nearest the south-east point of the horizon, which point is 45 degrees distant from the meridian, the sun's azimuth is an azimuth of 45 degrees, and the sun will appear in the south-east.

Imagine

Imagine the sun, as we have done before, to be placed directly over the globe.

In which case, a line going to the sun from any place on the surface of the globe, will have a vertical direction, and will go from that place vertically upwards.

If then we apply the artificial horizon to any place, the point of this horizon to which a vertical line is nearest, shews the sun's azimuth at that time.

It is observable, that the point of the horizon to which such a vertical line is nearest, will be at all times that point which is most elevated.

To exemplify this, let the globe be in the position of a right sphere, and let the artificial horizon be applied to London.

When London is at the western edge of the broad paper circle, which situation represents the time when the sun appears to rise, the eastern point of the artificial horizon being then most elevated, shews that the sun at his rising is due east.

Turn the globe, till London comes to the eastern edge of the broad paper circle, then the western point of the artificial horizon will be most elevated, shewing that the sun sets due west.

Now place the globe in the position of an oblique sphere; and if London be brought to the eastern or western side of the broad paper circle, the vertical line will depart more or less from the east and west points, in which case the sun is said to have more or less *AMPLITUDE*.

If the departure be northward, it is called northern amplitude; if southward, it is called southern amplitude.

In whatever position the globe be placed,* when London comes to the strong brass meridian, the most elevated part of the artificial horizon will be the south point of it.

Which shews that at noon the sun will always, and in all seasons, appear in the south.

* The globe is not supposed in this case, or under this view of things, ever to be elevated above the limits of the sun's declination.

P R O B L E M XVIII.

To illustrate the ancient distinction of different places on the earth, according to the diversity of the shadows of upright bodies at noon.

When the sun at noon is in the zenith of any place, the inhabitants of that place were by the ancients called *ASCH*; that is, without shadow: for the shadow of a man standing upright, when the sun is directly over his head, is not extended beyond that part of the earth which is directly under his body, and therefore will not be visible.

As the shadow of every opaque body is extended from the sun, it follows, that when the sun at noon is southward from the zenith of any place, the shadow of an inhabitant of that place, and indeed of every other opaque body, is extended towards the north.

But when the sun is northward from the zenith of any place, the shadow falls towards the south.

Those are called *AMPHISCII*, that have both kinds of meridian shadows.

Those whose meridian shadows are always projected one way, are termed *HETEROSCII*.

Rectify the globe to the summer solstice, and move the artificial horizon to the equator, the north point will be the most elevated at noon.

Which shews, that to those inhabitants who live at the equator, the sun will at this season appear to the north at noon, and their shadow will therefore be projected southwards.

But if you rectify the globe to the winter solstice, the south point being then the uppermost point at noon, the same persons will at noon have the sun on the south side of them, and will project their shadows northwards.

Thus they are *amphiscii*, projecting their shade both ways, which is the case of all the inhabitants within the tropics.

The artificial horizon remaining as before, rectify the globes to the times of the equinox, and you will find that when this horizon is under the
strong

strong brass meridian, a line going vertically upwards will be perpendicular to it, and consequently the sun will be directly over the heads of the inhabitants, and they will be *ascii*, having no noon shade; their shadow is in the morning projected directly westward, in the evening directly eastward,

The same thing will also happen to all the inhabitants who live between the tropics of Cancer and Capricorn, so that they are not only *ascii*, but *amphiscii* also.

Those who live without the tropics are *heteroscii*; those in north latitude have the noon shade always directed to the north, while those in south latitude have it always projected to the south.

The inhabitants of the polar circles are called *PERISCHII*, because as the sun goes round them continually, their shade goes round them likewise.

P R O B L E M X I X .

Of the ANTÆCI, PERIÆCI, and ANTIPODES.

These terms being often mentioned by geographical writers, it will be necessary to take some notice of them.

The ANTÆCI are two nations which are in or near the same meridian, the one in north, the other in south latitude.

They have, therefore, the same longitude, but not the same latitude; opposite seasons of the year, but the same hour of the day; the days of the one are equal to the nights of the other, and vice versa; when the days of the one are at the longest, they are shortest at the other.

When they look towards each other, the sun seems to rise on the right hand of the one, but on the left of the other. They have different poles elevated, and the stars that never set to the one, are never seen by the other.

PERIÆCI are also two opposite nations, situated on the same parallel of latitude.

They

They have, therefore, the same latitude, but differ 180 degrees in longitude; the same seasons of the year, but opposite hours of the day: for when it is twelve at night to the one, it is twelve at noon with the other. On the equinoctial days, the sun is rising to one, when it is setting to the other.

ANTIPODES are two nations diametrically opposite, which have opposite seasons and latitude, opposite hours and longitude.

The sun and stars rise to the one, when they set to the other, and that during the whole year, for they have the same horizon.

The day of the one is the night of the other, and when the day is longest with the one, the other has it's shortest day.

They have contrary seasons at the same time; different poles, but equally elevated; and those stars that are always above the horizon of one, are always under the horizon of the other.

To exemplify these particulars, bring the given place to the strong brass meridian; then in the opposite hemisphere, and under the same degree

of latitude with the given place, you will find the antœci.

The given place remaining under the meridian, set the horary index to XII; then turn the globe, till the other XII is under the index, then will you find the periœci under the same degree of latitude with the given place.

Thus the inhabitants of the south part of the Chili are antœci to the people of New England, whose periœci are those Tartars who dwell on the north borders of China, which Tartars have the said inhabitants of Chili for their antipodes.

This will become evident, by placing the globe in the position of a right sphere, and bringing those nations to the edge of the broad paper circle.

P R O B L E M XX.

The day of the month being given, to find all those places on the globe, over whose zenith the sun will pass on that day.

Rectify the terrestrial globe, by bringing the given day of the month on the back side of the strong brass meridian, to coincide with the plane of the broad paper circle ; observe the number of degrees of the brass meridian, which corresponds to the given day of the month.

This number of degrees, counted from the equator on the strong brass meridian towards the elevated pole, is the point over which the sun is vertical ; and all those places which pass under this point, have the sun directly vertical on the given day.

Example. Bring the 11th of May to coincide with the plane of the broad paper circle, and the said plane will cut 18 degrees for the elevation of the pole, which is equal to the sun's declination for that day, which being counted on the strong brass meridian towards the elevated pole, is the point over which the sun will be vertical ; and all
places

places that are under this degree, will have the sun on their zenith on the 11th of May.

Hence when the sun's declination is equal to the latitude of any place in the torrid zone, the sun will be vertical to those inhabitants that day; which furnishes us with another method of solving this problem.

P R O B L E M X X I ,

To find the sun's place on the broad paper circle,

Consider whether the year in which you seek the sun's place is biffextile, or whether it is the first, second, or third year after.

If it be the first year after biffextile, those divisions to which the numbers for the days of the month are affixed, are the divisions which are to be taken for the respective days of each month of that year at noon; opposite to which, in the circle of twelve signs, is the sun's place.

If it be the second year after biffextile, the first quarter of a day backwards, or towards the left hand, is the day of the month for that year, against which, as before, is the sun's place.

If

If it be the third year after biffextile, then three quarters of a day backwards is the day of the month for that year, opposite to which is the sun's place.

If the year in which you seek the sun's place be biffextile, then three quarters of a day backwards is the day of the month from the 1st of January to the 28th of February inclusive. The intercalary, or 29th day, is three-fourths of a day to the left hand from the 1st of March, and the 1st of March itself one quarter of a day forward, from the division marked 1; and so for every day in the remaining part of the leap-year; and opposite to these divisions is the sun's place.

In this manner the intercalary day is very well introduced every fourth year into the calendar, and the sun's place very nearly obtained, according to the Julian reckoning.

Thus,

A. D.			Sun's place.	Apr. 25.
1788	Biffextile	-	8	5 ^o 35
1789	First year after	-	8	5 21
1790	Second	-	8	5 6
1791	Third	-	8	4 55
				Upon

Upon my father's globes there are twenty-three parallels, drawn at the distance of one degree from each other on both sides the equator, which, with two other parallels at $23\frac{1}{2}$ degrees distance, include the ecliptic circle.

The two outermost circles are called the tropics ; that on the north side of the equator is called the tropic of Cancer, that which is on the south side, the tropic of Capricorn.

Now as the ecliptic is inclined to the equator, in an angle of $23\frac{1}{2}$ degrees, and is included between the tropics, every parallel between these must cross the ecliptic in two points, which two points shew the sun's place when he is vertical to the inhabitants of that parallel ; and the days of the month upon the broad paper circle answering to those points of the ecliptic, are the days on which the sun passes directly over their heads at noon, and which are sometimes called their two midsummer days.

It is usual to call the sun's diurnal paths parallels to the equator, which are therefore aptly represented by the above-mentioned parallel circles ; though his path is properly a spiral line, which he is continually describing all the year long,

long, appearing to move daily about a degree in the ecliptic.

P R O B L E M XXII.

To find the sun's declination, and thence the parallel of latitude corresponding thereto.

Find the sun's place for the given day in the broad paper circle, by the preceding problem, and seek that place in the ecliptic line upon the globe; this will shew the parallel of the sun's declination among the above-mentioned dotted lines, which is also the corresponding parallel of latitude; therefore, all those places through which this parallel passes, have the sun in their zenith at noon on the given day.

Thus on the 23d of May the sun's declination will be about 20 deg. 10 min.; and upon the 23d of August it will be 11 deg. 13 min. What has been said in the first part of this problem, will lead the reader to the solution of the following.

P R O B L E M XXIII.

To find the two days on which the sun is in the zenith of any given place that is situated between the two tropics.

That parallel of declination which passes through the given place, will cut the ecliptic line upon the globe in two points; which denote the sun's place, against which, on the broad paper circle, are the days and months required.

P R O B L E M XXIV.

The day and hour at any place being given, to find where the sun is vertical at that time.

Rectify the globe to the day of the month, see page 307, and you have the sun's declination; bring the given place to the meridian, and set the hour index to XII; turn the globe, till the index points to the given hour on the equator; then will the place be under the degree of the declination previously found.

Let the given place be London, and time the 11th day of May, at 4 min. past V in the afternoon; bring the 11th of May to coincide with
the

the broad paper circle, and opposite to it you will find 18 degrees of north declination; as London is the given place, you have only to turn the globe, till 4 min. past V westward of it, is on the meridian, when you will find Port-Royal, in Jamaica, under the 18th degree of the meridian, which is the place where the sun is vertical at that time.

P R O B L E M XXV.

The time of the day at any one place being given, to find all those places where at the same instant the sun is rising, setting, and on the meridian, and where he is vertical; likewise, those places where it is midnight, twilight, and dark night; as well as those places in which the twilight is beginning and ending; and also to find the sun's altitude at any hour in the illuminated, and his depression in the obscure, hemisphere.

Rectify the globe to the day of the month, on the back side of the strong brass meridian, and the sun's declination for that day; bring the given place to the strong brass meridian, and set the horary index to XII upon the equator; turn the

the globe from west to east, until the horary index points to the given time. Then

All those places which lie in the plane of the western side of the broad paper circle, see the sun rising, and at the same time those on the eastern side of it see him setting.

It is noon to all the inhabitants of those places under the upper half of the graduated side of the strong brass meridian, whilst at the same time those under the lower half have midnight.

All those places which are between the upper surface of the broad paper circle, and the wire circle under it, are in the twilight, which begins to all those places on the western side that are immediately under the wire circle; it's ends at all those which are in the plane of the paper circle.

The contrary happens on the eastern side; the twilight is just beginning to those places in which the sun is setting, and it's end is at the place just under the wire circle.

And

And those places which are under the twilight wire circle have dark night, unless the moon is favourable to them.

All places in the illuminated hemisphere have the sun's altitude equal to their distance from the edge of the enlightened disc, which is known by fixing the quadrant of altitude to the zenith, and laying it's graduated edge over any particular place.

The sun's depression is obtained in the same manner, by fixing the center of the quadrant at the nadir.

P R O B L E M XXVI.

To find all those places within the polar circles, on which the sun begins to shine, the time he shines constantly; when he begins to disappear, the length of his absence, as well as the first and last day of his appearance to those inhabitants; the day of the month, or latitude of the place, being given.

Bring the given day of the month on the back side of the strong brass meridian, to the plane of the broad paper circle; the sun is just then beginning

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ginning to shine on all those places which are in the parallel that just touches the edge of the broad paper circle, and will for several days seem to skim all around, and but a little above their horizon, just as it appears to us at it's setting; but with this observable difference, that whereas our setting sun appears in one part of the horizon only, by them it is seen in every part thereof; from west to south, thence east to north, and so to the west again.

Or if the latitude be given, elevate the globe to that latitude, and on the back of the strong brass meridian, opposite to the latitude, you obtain the day of the month, then all the other requisites are answered as above.

As the two concentric spaces which contain the days of the month on the back side of the strong brass meridian, are graduated to shew the opposite days of the year, at 180 degrees distance; when the given day is brought to coincide with the broad paper circle, it shews when the sun begins to shine on that parallel, which is the first day of it's appearance above the horizon of that parallel.

And

And the plane of the broad paper circle cuts the day of the month on the opposite concentric space, when the sun begins to disappear to those inhabitants.

The length of the longest day is obtained by reckoning the number of days between the two opposite days found as above, and their difference from 365 gives the length of their longest night.

P R O B L E M XXVII.

To make use of the globe as a tellurian, or that kind of orrery which is chiefly intended to illustrate the phænomena that arise from the annual and diurnal motions of the earth.

Describe a circle with chalk upon the floor, as large as the room will admit of, so that the globe may be moved round upon it; divide this circle into twelve parts, and mark them with the characters of the twelve signs, as they are engraved upon the broad paper circle; placing ♊ at the north, ♋ at the south, ♈ in the east, and ♎ in the west: the mariner's compass under the globe will direct the situation of these points, if the variation of the magnetic needle be attended to.

Note, At London the variation is between 23 and 24 degrees from the north westward.

Elevate the north pole of the globe, so that $66\frac{1}{2}$ degrees on the strong brass meridian may coincide with the surface of the broad paper circle, and this circle will then represent the plane of the ECLIPTIC, or a plane coinciding with the earth's orbit.

Set a small table, or a stool, over the center of the chalked circle, to represent the sun, and place the terrestrial globe upon it's circumference over the point marked $\vee\wp$, with the north pole facing the imaginary sun, and the north end of the needle pointing to the variation; and the globe will be in the position of the earth with respect to the sun at the time of the summer solstice, about the 21st of June; and the earth's axis, by this rectification of the globe, is inclined to the plane of the large chalked circle, as well as to the plane of the broad paper circle, in an angle of $66\frac{1}{2}$ degrees; a line, or string, passing from the center of the imaginary sun to that of the globe, will represent a central solar ray connecting the centers of the earth and sun: this ray will fall upon the first point of Cancer, and describe that circle, shewing it to be the sun's place upon
the

the terrestrial ecliptic, which is the same as if the sun's place, by extending the string, was referred to the opposite side of the chalked circle, here representing the earth's path in the heavens.

If we conceive a plane to pass through the center of the globe, and the sun's center, it will also pass through the points of Cancer and Capricorn, in the terrestrial and celestial ecliptic; the central solar ray, in this position of the earth, is also in that plane; this can never happen but at the times of the solstice.

If another plane be conceived to pass through the center of the globe at right angles to the central solar ray, it will divide the globe into two hemispheres; that next the center of the chalked circle will represent the earth's illuminated disc, the contrary side of the same plane will at the same time shew the obscure hemisphere.

The reader may realize this second plane by cutting away a semicircle from a sheet of card paste-board, with a radius of about $1\frac{1}{2}$ tenth of an inch greater than that of the globe itself. *

Y 3

If

* Or he may have a plane made of wood for this purpose.

If this plane be applied to $66\frac{1}{2}$ degrees upon the strong brass meridian, it will be in the pole of the ecliptic ; and in every situation of the globe round the circumference of the chalked circle, it will afford a lively and lasting idea of the various phænomena arising from the parallelism of the earth's axis, and in particular the daily change of the sun's declination, and the parallels thereby described.

Let the globe be removed from $V\gamma$ to \approx , and the needle pointing to the variation as before, will preserve the parallelism of the earth's axis ; then it will be plain, that the string, or central solar ray, will fall upon the first point of Leo, six signs distant from, but opposite to the sign \approx , upon which the globe stands ; the central solar ray will now describe the 20th parallel of north declination, which will be about the 23d of July.

If the globe be moved in this manner from point to point round the circumference of the chalked circle, and care be taken at every removal that the north end of the magnetic needle, when settled, points to the degree of the variation, the north pole of the globe will be observed to recede from the line connecting the centers of the earth and sun, until the globe is placed upon the point
Cancer ;

Cancer; after which, it will at every removal tend more and more towards the said line, till it comes to Capricorn again.

P R O B L E M XXVIII.

To rectify either globe to the latitude and horizon of any place.

If the place be in north latitude, raise the north pole; if in south latitude, raise the south pole, until the degree of the given latitude, reckoned on the strong brass meridian under the elevated pole, cuts the plane of the broad paper circle; then this circle will represent the horizon of that place.

P R O B L E M XXIX.

To rectify for the sun's place.

After the former rectification, bring the degrees of the sun's place in the ecliptic line upon the globe to the strong brass meridian, and set the horary index to that XIIth hour upon the equator which is most elevated.

Or, if the sun's place is to be retained, to answer various conclusions, bring the graduated edge of the moveable meridian to the degree of the sun's place in the ecliptic, and slide the wire which crosses the center of the artificial horizon thereto; then bring it's center, which is the intersection of the aforesaid wire, and graduated edge of the moveable meridian, under the strong brass meridian as before, and set the horary index to that XII on the equator which is most elevated.

P R O B L E M X X X .

To rectify for the zenith of any place.

After the first rectification, screw the nut of the quadrant of altitude so many degrees from the equator, reckoned on the strong brass meridian towards the elevated pole, as that pole is raised above the plane of the broad paper circle, and that point will represent the zenith of the place.

Note, The zenith and nadir are the poles of the horizon, the former being a point directly over our heads, and the latter, one directly under our feet.

If,

If, when the globe is in this state, we look on the opposite side, the plane of the horizon will cut the strong brass meridian at the complement of the latitude, which is also the elevation of the equator above the horizon.

OF THE SOLUTION OF SOME PROBLEMS, IN WHICH
THE BROAD PAPER CIRCLE IS CONSIDERED AS
THE RATIONAL HORIZON.

P R O B L E M XXXI.

To shew at one view upon the terrestrial globe for any given place, the sun's meridian altitude, his amplitude, or point of the compass, on which he rises and sets every day in the year.

Rectify the globe to the latitude of the given place, bring that place to the strong brass meridian, and set the horary index to XII; screw the quadrant of altitude to the zenith of the horizon, and bring it to the brass meridian.

You will then at one view see the sun's meridian altitude on every degree of the sun's declination for the whole year, cut by the graduated edge of the quadrant of altitude, on the dotted parallels.

These

These dotted parallels at the same instant also cut the edge of the broad paper circle, now representing the horizon, in the point of the compass, or amplitude, on which the sun is seen to rise on the east, or to set on the west side of the horizon, for every degree of declination throughout the year.

If you trace any of those parallels to the ecliptic line, you have the sun's place when he is upon that declination, and thence the day and month upon the horizon.

Also, the knowledge of the sun's place in the ecliptic line, shews the sun's declination for that time amongst the dotted parallels.

P R O B L E M XXXII.

To shew at one view upon the terrestrial globe the length of the days and nights at any particular place, for all times of the year.

Rectify the globe to the latitude of the place, and the broad paper circle will represent the horizon; and the upper part of the dotted parallels of declination, which are here also parallels of latitude, will represent the diurnal arches.

Whence

Whence we may obtain the number of hours each of them contains, which is the solution of the problem. To illustrate this,

Elevate the globe to the position of a right sphere, and you will, with one glance of the eye, see that all the dotted parallels of declination, as well as the equator itself, are cut by the horizon into two equal parts.

Therefore the inhabitants on the equinoctial line have their days and nights twelve hours long; that is, the sun is never more, nor ever less than twelve hours above their horizon, during his apparent passage from the tropic of Cancer to the tropic of Capricorn, and thence to Cancer again.

All the fixed stars have the same apparent motion to the equatorial inhabitants; that is, they rise and set, continue above, and are depressed below the horizon of any place upon the equator, exactly twelve hours.

Raise the north pole of the globe a few degrees of latitude at a time, and you will see the diurnal arches increase in length, until the pole is elevated to $66\frac{1}{2}$ degrees above the horizon; then the parallel of the sun's greatest declination will be as far
from

from the equator as the place itself is from the pole; and this parallel is the tropic of Cancer, which will just touch the horizon in the north point.

And on the contrary, we may observe that the southern parallels of declination continually shorten, as the northern ones lengthen, until they come to the tropic of Capricorn.

Rectify the globe to the latitude of London, $51\frac{1}{2}$ degrees north; when the sun is in the tropic of Cancer, the day is about $16\frac{1}{2}$ hours; as he recedes from thence, the days shorten, as the length of the diurnal arches of the parallels shorten, until the sun comes to Capricorn, and then the days are at the shortest, being of the same length with the nights when the sun was in Cancer, viz. about $7\frac{1}{2}$ hours.

Rectify the globe to the altitude of the northern polar circle, and you will find, when the sun is in Cancer, he touches the horizon on that day without setting, being completely twenty-four hours above the horizon; and when he is in Capricorn, he once appears in the horizon, but does not rise for the space of twenty-four hours; when he is upon any other parallel of declination, the

the days are longer or shorter, as that parallel is nearer to, or farther from the equator.

Elevate the globe to the latitude of 80 degrees north, at which time let the sun's declination be 10 degrees north, he then apparently seems to turn round above the horizon without setting, and never sets from this point to Cancer, until in his return, after he has again passed this parallel of declination.

In the same manner, when his declination is 10 degrees south, he is just seen at noon in the horizon, and disappears from that time in his southerly motion, till his return to the same point.

Elevate the north pole to 90 degrees, or in the zenith, then the globe will be in the position of a parallel sphere, and the equinoctial line will coincide with the plane of the horizon; consequently all the northern parallels are above, and all the southern parallels below the horizon; therefore, the polar inhabitants, if any there be, have but one day and one night throughout the year; their day, when the sun is in his northern, and their night, when he is in his southern declination.

P R O B L E M XXXIII.

To find the angle of position of places.

The angle of position is that formed between the meridian of one of the places, and a great circle passing through the other place.

Rectify the globe to the latitude and zenith of one of the places, bring that place to the strong brass meridian, set the graduated edge of the quadrant to the other place, and the number of degrees contained between it and the strong brass meridian, is the measure of the angle sought. Thus,

The angle of position between the meridian of Cape Clear, in Ireland, and St. Augustine, in Florida, is about 82 degrees north westerly; but the angle of position between St. Augustine and Cape Clear, is only about 46 degrees north easterly.

Hence it is plain, that the line of position, or azimuth, is not the same from either place to the other, as the romb lines are.

P R O B L E M XXXIV.

To find the bearing of one place from another.

The bearing of one sea-port from another is determined by a kind of spiral, called a romb-line, passing from one to the other, so as to make equal angles with all the meridians it passeth by; therefore, if both places are situated on the same parallel of latitude, their bearing is either east or west from each other; if they are upon the same meridian, they bear north and south from one another; if they lie upon a romb-line, their bearing is the same with it; if they do not, observe to which romb-line the two places are nearest parallel, and that will shew the bearing sought.

Example. Thus the bearing of the Lizard point from the island of Bermudas, is nearly E. N. E.; and that of Bermudas from the Lizard is W. S. W. both nearly upon the same romb-line, but in contrary directions.

OF THE SOLUTION OF PROBLEMS, BY EXPOSING
THE GLOBE TO THE SUN'S RAYS.

In the year 1679, J. Moxon published a treatise on what he called "THE ENGLISH GLOBE; being (says he) a stabil and immobil one, performing what the ordinary globes do, and much more; invented and described by the Right Hon. the Earl of Castlemaine." This globe was designed to perform, by being merely exposed to the sun's rays, all those problems which in the usual way are solved by the adventitious aid of brazen meridians, hour indexes, &c.

My father thought that this method might be useful, to ground more deeply in the young pupil's mind, those principles which the globes are intended to explain; and by giving him a different view of the subject, improve and strengthen his mind; he therefore inserted on his globes some lines, for the purpose of solving a few problems in Lord Castlemaine's manner.

It appears to me, from a copy of Moxon's publication, which is in my possession, that the Earl of Castlemaine projected a new edition of his works, as the copy contains a great number of corrections, many alterations, and some additions.

ditions. It is not very improbable, that at some future day I may re-publish this curious work, and adapt a small globe for the solution of the problems.

The meridians on our new terrestrial globes being secondaries to the equator, are also hour circles, and are marked as such with Roman figures, under the equator, and at the polar circles. But there is a difference in the figures placed to the same hour circle; if it cuts the III^d hour upon the polar circles, it will cut the IXth hour upon the equator, which is six hours later, and so of all the rest.

Through the great Pacific sea, and the intersection of Libra, is drawn a broad meridian from pole to pole; it passes through the XIIth hour upon the equator, and the VIth hour upon each of the polar circles; this hour circle is graduated into degrees and parts, and numbered from the equator towards either pole.

There is another broad meridian passing through the Pacific sea, at the IXth hour upon the equator, and the III^d hour upon each polar circle; this contains only one quadrant, or 90 degrees; the numbers annexed to it begin at the

Z

northern

northern polar circle, and end at the tropic of Capricorn.

Here we must likewise observe, there are 23 concentric circles drawn upon the terrestrial globe within the northern and southern polar circles, which for the future we shall call polar parallels; they are placed at the distance of one degree from each other, and represent the parallels of the sun's declination, but in a different manner from the 47 parallels between the tropics.

The following problems require the globe to be placed upon a plane that is level, or truly horizontal, which is easily attained, if the floor, pavement, gravel-walk in the garden, &c. should not happen to be horizontal.

A flat seasoned board, or any box which is about two feet broad, or two feet square, if the top be perfectly flat, will answer the purpose; the upper surface of either may be set truly horizontal, by the help of a pocket spirit level, or plumb rule, if you raise or depress this or that side by a wedge or two, as the spirit level shall direct; if you have a meridian line drawn on the place over which you substitute this horizontal plane, it may be readily transferred from thence

to

to the surface just levelled ; this being done, we are prepared for the solution of the following problems.

It will be necessary to define a term we are obliged to make use of in the solution of these problems, namely, the SHADE OF EXTUBERANCY : by this is meant that shade which is caused by the sphericity of the globe, and answers to what we have heretofore named the terminator, defining the boundaries of the illuminated and obscure parts of the globe ; this circle was, in the solution of some of the foregoing problems, represented by the broad paper circle, but here realized by the rays of the sun.

P R O B L E M XXXV.

To observe the sun's altitude (by the terrestrial globe) when he shines bright, or when he can but just be discerned through a cloud.

Elevate the north pole of the globe to $66\frac{1}{2}$ degrees ; bring that meridian, or hour circle, which passes through the IXth hour upon the equator, under the graduated side of the strong brass meridian ; the globe being now set upon the horizontal plane, turn it about thereon, frame and

all, that the shadow of the strong brass meridian may fall directly under itself; or in other words, that the shade of it's graduated face may fall exactly upon the aforefaid hour circle; at that instant the shade of extuberancy will touch the true degree of the sun's altitude upon that meridian, which passes through the IXth hour upon the equator, reckoned from the polar circle, the most elevated part of which will then be in the zenith of the place where this operation is performed, and is the same whether it should happen to be either in north or south latitude.

Thus we may, in an easy and natural manner, obtain the altitude of the sun, at any time of the day, by the terrestrial globe; for it is very plain, when the sun rises, he brushes the zenith and nadir of the globe by his rays; and as he always illuminates half of it, (or a few minutes more, as his globe is considerably larger than that of the earth) therefore when the sun is risen a degree higher, he must necessarily illuminate a degree beyond the zenith, and so on proportionably from time to time.

But as the illuminated part is somewhat more than half, deduct 13 minutes from the shade of

extuberancy, and you have the sun's altitude with tolerable exactness.

If you have any doubt how far the shade of extuberancy reaches, hold a pin, or your finger, on the globe, between the sun and point in dispute, and where the shade of either is lost, will be the point sought.

When the sun does not shine bright enough to cast a shadow.

Turn the meridian of the globe towards the sun, as before, or direct it so that it may lie in the same plane with it, which may be done if you have but the least glimpse of the sun through a cloud; hold a string in both hands, it having first been put between the strong brass meridian and the globe; stretch it at right angles to the meridian, and apply your face near to the globe, moving your eye lower and lower, till you can but just see the sun; then bring the string held as before to this point upon the globe, that it may just obscure the sun from your sight, and the degree on the aforesaid hour circle, which the string then lies upon, will be the sun's altitude required, for his rays would shew the same point if he shone out bright.

Note, The moon's altitude may be observed by either of these methods, and the altitude of any star by the last of them.

P R O B L E M X X X V I .

To place the terrestrial globe in the sun's rays, that it may represent the natural position of the earth, either by a meridian line, or without it.

If you have a meridian line, set the north and south points of the broad paper circle directly over it, the north pole of the globe being elevated to the latitude of the place, and standing upon a level plane, bring the place you are in under the graduated side of the strong brass meridian, then the poles and parallel circles upon the globe will, without sensible error, correspond with those in the heavens, and each point, kingdom, and state, will be turned towards the real one which it represents.

If you have no meridian line, then the day of the month being known, find the sun's declination as before instructed, which will direct you to the parallel of the day, amongst the polar parallels,

els, reckoned from either pole towards the polar circle ; which you are to remember.

Set the globe upon your horizontal plane in the sun-shine, and put it nearly north and south by the mariner's compass, it being first elevated to the latitude of the place, and the place itself brought under the graduated side of the strong brass meridian ; then move the frame and globe together, till the shade of extuberancy, or term of illumination, just touches the polar parallel for the day, and the globe will be settled as before ; and if accurately performed, the variation of the magnetic needle will be shewn by the degree to which it points in the compass box.

And here observe, if the parallel for the day should not happen to fall on any one of those drawn upon the globe, you are to estimate a proportionable part between them, and reckon that the parallel of the day. If we had drawn more, the globe would have been confused.

The reason of this operation is, that as the sun illuminates half the globe, the shade of extuberancy will constantly be 90 degrees from the point wherein the sun is vertical.

If the sun be in the equator, the shade and illumination must terminate in the poles of the world; and when he is in any other diurnal parallel, the terms of illumination must fall short of, or go beyond either pole, as many degrees as the parallel which the sun describes that day is distant from the equator; therefore, when the shade of extuberancy touches the polar parallel for the day, the artificial globe will be in the same position, with respect to the sun, as the earth really is, and will be illuminated in the same manner.

P R O B L E M XXXVII.

To find naturally the sun's declination, diurnal parallel, and his place thereon.

The globe being set upon an horizontal plane, and adjusted by a meridian line or otherwise, observe upon which, or between which polar parallel the term of illumination falls; it's distance from the pole is the degree of the sun's declination; reckon this distance from the equator among the larger parallels, and you have the parallel which the sun describes that day; upon which if you move a card, cut in the form of a double square, until it's shadow falls under itself, you will obtain the very place upon that parallel
over

over which the sun is vertical at any hour of that day, if you set the place you are in under the graduated side of the strong brass meridian.

Note, The moon's declination, diurnal parallel and place, may be found in the same manner. Likewise, when the sun does not shine bright, his declination, &c. may be found by an application in the manner of problem 35.

P R O B L E M XXXVIII.

To find the sun's azimuth naturally.

If a great circle, at right angles to the horizon, passes through the zenith and nadir, and also through the sun's center, it's distance from the meridian in the morning or evening of any day, reckoned upon the degrees on the inner edge of the broad paper circle, will give the azimuth required.

M E T H O D I.

Elevate either pole to the position of a parallel sphere, by bringing the north pole in north latitude, and the south pole in south latitude, into the zenith of the broad paper circle, having first placed

placed the globe upon your meridian line, or by the other method before prescribed; hold up a plumb line, so that it may pass freely near the outward edge of the broad paper circle, and move it so that the shadow of the string may fall upon the elevated pole; then cast your eye immediately to it's shadow on the broad paper circle, and the degree it there falls upon is the sun's azimuth at that time, which may be reckoned from either the south or north points of the horizon.

M E T H O D II.

If you have only a glimpse, or faint sight of the sun, the globe being adjusted as before, stand on the shady side, and hold the plumb line on that side also, and move it till it cuts the sun's center, and the elevated pole at the same time; then cast your eye towards the broad paper circle, and the degree it there cuts is the sun's azimuth, which must be reckoned from the opposite cardinal point.

P R O B L E M XXXIX.

To shew that in some places of the earth's surface, the sun will be twice on the same azimuth in the morning, twice on the same azimuth in the afternoon : or, in other words,

When the declination of the sun exceeds the latitude of any place, on either side of the equator, the sun will be on the same azimuth twice in the morning, and twice in the afternoon.

Thus, suppose the globe rectified to the latitude of Antigua, which is in about 17 deg. of north latitude, and the sun to be in the beginning of Cancer, or to have the greatest north declination ; set the quadrant of altitude to the 21st degree north of the east in the horizon, and turn the globe upon it's axis, the sun's center will be on that azimuth at 6 h. 30 min. and also at 10 h. 30 min. in the morning. At 8 h. 30 min. the sun will be as it were stationary, with respect to it's azimuth, for some time ; as will appear by placing the quadrant of altitude to the 17th degree north of the east in the horizon. If the quadrant be set to the same degrees north of the west, the sun's center will cross it twice as it approaches the horizon in the afternoon.

This

This appearance will happen more or less to all places situated in the torrid zone, whenever the sun's declination exceeds their latitude ; and from hence we may infer, that the shadow of a dial, whose gnomon is erected perpendicular to an horizontal plane, must necessarily go back several degrees on the same day.

But as this can only happen within the torrid zone, and as Jerufalem lies about 8 degrees to the north of the tropic of Cancer, the retrocession of the shadow on the dial of Ahaz, at Jerufalem, was, in the strictest signification of the word, miraculous.

P R O B L E M X L.

To observe the hour of the day in the most natural manner, when the terrestrial globe is properly placed in the sun-shine,

There are many ways to perform this operation with respect to the hour, three of which are here inserted, being general to all the inhabitants of the earth ; a fourth is added, peculiar to those of London, which will answer, without sensible error, at any place not exceeding the distance of 60 miles from this capital,

1st, By

1st, By a natural stile.

Having rectified the globe as before directed, and placed it upon an horizontal plane over your meridian line, or by the other method, hold a long pin upon the illuminated pole, in the direction of the polar axis, and it's shadow will shew the hour of the day amongst the polar parallels.

The axis of the globe being the common section of the hour circles, is in the plane of each; and as we suppose the globe to be properly adjusted, they will correspond with those in the heavens; therefore, the shade of a pin, which is the axis continued, must fall upon the true hour circle.

2ndly, By an artificial stile.

Tye a small string, with a noose, round the elevated pole, stretch it's other end beyond the globe, and move it so that the shadow of the string may fall upon the depressed axis; at that instant it's shadow upon the equator will give the solar hour to a minute.

But remember, that either the autumnal or vernal equinoctial colure must first be placed under the graduated side of the strong brass meridian,

ridian, before you observe the hour, each of these being marked upon the equator with the hour XII.

The string in this last case being moved into the plane of the sun, corresponds with the true hour circle, and consequently gives the true hour.

3dly, Without any stile at all.

Every thing being rectified as before, look where the shade of extuberancy cuts the equator, the colure being under the graduated side of the strong brass meridian, and you obtain the hour in two places upon the equator, one of them going before, and the other following the sun.

Note, If this shade be dubious, apply a pin, or your finger, as before directed.

The reason is, that the shade of extuberancy being a great circle, cuts the equator in half, and the sun, in whatsoever parallel of declination he may happen to be, is always in the pole of the shade; consequently the confines of light and shade will shew the true hour of the day.

4thly,

4thly, Peculiar to the inhabitants of London, and any place within the distance of sixty miles from it.

The globe being every way adjusted as before, and London brought under the graduated side of the strong brass meridian, hold up a plumb line, so that it's shadow may fall upon the zenith point, (which in this case is London itself) and the shadow of the string will cut the parallel of the day upon that point to which the sun is then vertical, and that hour circle upon which this intersection falls, is the hour of the day; and as the meridians are drawn within the tropics, at 20 minutes distance from each other, the point cut by the intersection of the string upon the parallel of the day, being so near the equator, may, by a glance of the observer's eye, be referred thereto, and the true time obtained to a minute.

The plumb line thus moved, is the azimuth; which, by cutting the parallel of the day, gives the sun's place, and consequently the hour circle which intersects it.

From this last operation results a corollary, that gives a second way of rectifying the globe to the sun's rays.

If

If the azimuth and shade of the illuminated axis agree in the hour when the globe is rectified, then making them thus to agree, must rectify the globe.

C O R O L L A R Y.

Another method to rectify the globe to the sun's rays.

Move the globe, till the shadow of the plumb line, which passes through the zenith, cuts the same hour on the parallel of the day, that the shade of the pin, held in the direction of the axis, falls upon, amongst the polar parallels, and the globe is rectified.

The reason is, that the shadow of the axis represents an hour circle; and by it's agreement in the same hour, which the shadow of the azimuth string points out, by it's intersection on the parallel of the day, it shews the sun to be in the plane of the said parallel; which can never happen in the morning on the eastern side of the globe, nor in the evening on the western side of it, but when the globe is rectified.

This rectification of the globe is only placing it in such a manner, that the principal great circles, and points, may concur and fall in with those of the heavens.

The many advantages arising from these problems, relating to the placing of the globe in the sun's rays, the tutor will easily discern, and readily extend to his own, as well as to the benefit of his pupil.



THE GENERAL PRINCIPLES OF
D I A L L I N G

ILLUSTRATED BY THE
TERRESTRIAL GLOBE.

THE art of dialling is of very ancient origin, and was in former times cultivated by all who had any pretensions to science; and before the invention of clocks and watches, it was of the highest importance, and is even now used to correct and regulate them.

It teaches us, by means of the sun's rays, to divide time into equal parts, and to represent on any given surface the different circles into which, for convenience, we suppose the heavens to be divided, but principally the hour circles.

The

The hours are marked upon a plane, and pointed out by the interposition of a body, which receiving the light of the sun, casts a shadow upon the plane. This body is called the axis, when it is parallel to the axis of the world. It is called the style, when it is so placed that only the end of it coincides with the axis of the earth; in this case, it is only this point which marks the hours.

Among the various pleasing and profitable amusements which arise from the use of globes, that of dialling is not the least. By it the pupil will gain satisfactory ideas of the principles on which this branch of science is founded; and it will reward, with abundance of pleasure, those that chuse to exercise themselves in the practice of it.

If we imagine the hour circles of any place, as London, to be drawn upon the globe of the earth, and suppose this globe to be transparent, and to revolve round a real axis, which is opaque, and casts a shadow; it is evident, that whenever the plane of any hour semicircle points at the sun, the shadow of the axis will fall upon the opposite semicircle.*

* Long's Astronomy, vol. 1, page 82.

Let a P C p, fig. 1, plate XII. represent a transparent globe; a b c d e f g the hour semicircles; it is clear, that if the semicircle P a p points at the sun, the shadow of the axis will fall upon the opposite semicircle.

If we imagine any plane to pass through the center of this transparent globe, the shadow of half the axis will always fall upon one side or the other of this intersecting plane.

Thus let A B C D be the plane of the horizon of London; so long as the sun is above the horizon, the shadow of the upper half of the axis will fall somewhere upon the upper side of the plane A B C D; when the sun is below the horizon of London, then the shadow of the lower half of the axis E falls upon the lower side of the plane.

When the plane of any hour semicircle points at the sun, the shadow of the axis marks the respective hour line upon the intersecting plane. The hour line is therefore a line drawn from the center of the intersecting plane, to that point where this plane is cut by the semicircle opposite to the hour semicircle.

Thus

Thus let A B C D, fig. 1, plate XII. the horizon of London, be the intersecting plane; when the meridian of London points at the sun, as in the present figure, the shadow of the half axis P E falls upon the line E B, which is drawn from E, the center of the horizon, to the point where the horizon is cut by the opposite semicircle; therefore, E B is the line for the hour of twelve at noon.

By the same method the rest of the hour lines are found, by drawing for every hour a line from the center of the intersecting plane, to that semicircle which is opposite to the hour semicircle.

Thus fig. 2, plate XII. shews the hour lines drawn upon the plane of the horizon of London, with only so many hours as are necessary; that is, those hours, during which the sun is above the horizon of London, on the longest day in summer.

If when the hour lines are thus found, the semicircles be taken away, as the scaffolding is when the house is built, what remains, as in fig. 2, will be an HORIZONTAL DIAL for London.

If, instead of twelve hour circles as above described, we take twice that number, we may by the points, where the intersecting plane is cut by them, find the lines for every half hour; if we take four times the number of hour circles, we may find the lines for every quarter of an hour, and so on progressively.

We have hitherto considered the horizon of London as the intersecting plane, by which is seen the method of making an horizontal dial. If we take any other plane for the intersecting plane, and find the points where the hour semi-circles pass through it, and draw lines from the center of the plane to those points, we shall have the hour lines for that plane.

Fig. 3, plate XII. shews how the hour lines are found upon a south plane, perpendicular to the horizon. Fig. 4 shews a south dial, with it's hour lines, without the semicircle, by means whereof they are found.

The GNOMON of every sun-dial represents the axis of the earth, and is therefore always placed parallel to it, whether it be a wire, as in the figure before us, or the edge of a brass plate, as in a common horizontal dial,

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The whole earth, as to it's bulk, is but a POINT, if compared to it's distance from the sun; therefore, if a small sphere of glafs be placed on any part of the earth's surface, so that it's axis be parallel to the axis of the earth, and the sphere have such lines upon it, and such planes within it, as above described, it will shew the hour of the day as truly as if it were placed at the center of the earth, and that the shell of the earth were as transparent as glafs.

A wire sphere, with a thin flat plate of brass within it, is often made use of to explain the principles of dialling.

From what has been said, it is clear that dialling depends on finding where the shadow of a strait wire, parallel to the axis of the earth, will fall upon a given plane, every hour, half hour, &c. the hour lines being found as above described, which we shall proceed to exemplify by the globe.

Every dial plane (that is, the plane surface on which a dial is drawn) represents the plane of a great circle, which circle is an HORIZON to some country or other.

The center of the dial represents the center of the earth ; and the gnomon which casts the shade represents the axis, and ought to point directly to the poles of the equator.

The planes upon which dials are delineated may be either, 1. parallel to the horizon ; 2. perpendicular to the horizon ; or, 3. cutting it at oblique angles.

P R O B L E M XLI.

To construct an horizontal dial for any given latitude, by means of the terrestrial globe.

Elevate the globe to the latitude of the place ; then bring the first meridian under the graduated edge of the strong brazen one, which will then be over the hour XII, or the equator. As our globes have meridians drawn through every 15 degrees of the equator, these meridians will represent the true circles of the sphere, and will intersect the horizon of the globe, in certain points on each side of the meridian. The distance of these points from the meridian, must be carefully noted down upon a piece of paper, as will be seen in the example. The pupil need not, however, take out into his table the distances
further

further than from XII to VI, which is just 90 degrees; for the distances of XI, X, IX, VIII, VII, VI, in the forenoon, are the same from XII as the distances of I, II, III, IV, V, VI, in the afternoon; and these hour lines continued through the center will give the opposite hour lines on the other half of the dial.

No more hour lines need be drawn than what answer to the sun's continuance above the horizon, on the longest day of the year, in the given latitude.

Example. Suppose the given place to be London, whose latitude is 51 deg. 30 min. north.

Elevate the north pole of the globe to $51\frac{1}{2}$ degrees above the horizon; then will the axis of the globe have the same elevation above the broad paper circle, as the gnomon of the dial is to have above the plane thereof.

Turn the globe, till the first meridian (which on English globes passes through London) is under the graduated side of the strong brazen meridian; then observe and note the points where the hour circles intersect the horizon; and as on

our

our globes the inner graduated circle, on the broad paper circle, begins from the two fixes, or east and west, we shall begin from thence, calling the hour - - VI 0° 0

we shall find the other hours intersecting the horizon at the following degrees: V 18° 54

IV 36 24

III 51 57

II 65 41

I 78 9

which are the respective distances of the above hours from VI upon the plane of the horizon.

To transfer these, and the rest of the hours, upon an horizontal plane, draw the parallel right lines a c and b d, fig. 5, plate XII. upon that plane, as far from each other as is equal to the intended thickness of the gnomon of the dial, and the space included between them will be the meridian, or twelve o'clock line upon the dial; cross this meridian at right angles by the line g h, which will be the six o'clock line; then setting one foot of your compasses in the intersection a, describe the quadrant g c with any convenient radius, or opening of the compasses; after this, set one foot of the compasses in the intersection b, as a center, and with the same radius describe the

the quadrant fh ; then divide each quadrant into 90 equal parts, or degrees, as in the figure.

Because the hour lines are less distant from each other about noon, than in any other part of the dial, it is best to have the centers of the quadrants at some distance from the center of the dial plane, in order to enlarge the hour distances near XII; thus the center of the plane is at A , but the center of the quadrants is at a and b .

Lay a rule over $78^{\circ} 9'$, and the center b , and draw there the hour line of I. Through b , and $65\ 41$, gives the hour line of II. Through b , and $51\ 57$, that of III. Through the same center, and $36\ 24$, we obtain the hour line of IV. And through it, and $18\ 54$, that of V. And because the sun rises about four in the morning, continue the hour lines of IV and V in the afternoon, through the center b to the opposite side of the dial.

Now lay a rule successively to the center a of the quadrant cg , and the like elevations or degrees of that quadrant, $78,9$, $65,41$, $51,57$, $36,24$, $18,54$, which will give the forenoon hours of XI, X, IX, VIII, and VII; and because the sun does not set before VIII in the evening

evening on the longest days, continue the hour lines of VII and VIII in the afternoon, and all the hour lines will be finished on this dial.

Lastly, through $51\frac{1}{2}$ degrees on either quadrant, and from it's center, draw the right line a g for the axis of the gnomon a g i, and from g let fall the perpendicular g i upon the meridian line a i, and there will be a triangle made, whose sides are a g, g i, and i a; if a plate similar to this triangle be made as thick as the distance between the lines a c and b d, and be set upright between them, touching at a and b, the line a g will, when it is truly set, be parallel to the axis of the world, and will cast a shadow on the hour of the day.

The trouble of dividing the two quadrants may be saved, by using a line of chords, which is always placed upon every scale belonging to a case of instruments.

P R O B L E M X L I I I .

To delineate a direct south dial for any given latitude, by the globe.

Let us suppose a south dial for the latitude of London.

Elevate the pole to the co-latitude of your place, and proceed in all respects as above taught for the horizontal dial, from VI in the morning to VI in the afternoon, only the hours must be reversed, as in fig. 3, plate XII. ; and the hypotenuse ag of the gnomon agf , must make an angle with the dial plane to the co-latitude of the place.

As the sun can shine no longer than from VI in the morning to VI in the evening, there is no occasion for having more than twelve hours upon this dial.

In solving this problem, we have considered our vertical south dial for the latitude of London, as an horizontal one for the complement of that latitude, or 38 deg. 30 min. ; all direct vertical dials may be thus reduced to horizontal ones, in the same manner. The reason of this will be evident,

evident, if the globe be elevated to the latitude of London; for by fixing the quadrant of altitude to the zenith, and bringing it to intersect the horizon in the east point, it will point out the plane of the proposed dial.

This plane is at right angles to the meridian, and perpendicular to the horizon; and it is clear, from the bare inspection of the globe thus elevated, that it's axis forms an angle with this plane, which is just the complement of that which it forms with the horizon, and is therefore just equal to the co-latitude of the place, and that therefore it is most simple to rectify the globe to that co-latitude.

The north vertical dial is the same with the south, only the style must point upwards, and that many of the hours from it's direction can be of no use.

P R O B L E M XLIII.

To make an erect dial, declining from the south towards the east or west.

Elevate the pole to the latitude of the place, and screw the quadrant of altitude to the zenith.

Then if your dial declines towards the east, (which we shall suppose in the present instance) count in the horizon the degrees of declination, from the east point towards the north, and bring the lower end of the quadrant to coincide with that degree of declination at which the reckoning ends.

Then bring the first meridian under the graduated edge of the strong brazen meridian, which strong meridian will be the horary index.

Now turn the globe westward, and observe the degrees cut in the quadrant of altitude by the first meridian, while the hours XI, X, IX, &c. in the forenoon, pass successively under the brazen one; and the degrees thus cut on the quadrant by the first meridian, are the respective distances of the forenoon hours, from XII, on the plane of the quadrant.

For

For the afternoon hours, turn the quadrant of altitude round the zenith, until it comes to the degree in the horizon, opposite to that where it was placed before, namely, as far from the west towards the south, and turn the globe eastward; and as the hours I, II, III, &c. pass under the strong brazen meridian, the first meridian will cut on the quadrant of altitude the number of degrees from the zenith, that each of the hours is from XII on the dial.

When the first meridian goes off the quadrant at the horizon, in the forenoon, the hour index will shew the time when the sun comes upon this dial; and when it goes off the quadrant in the afternoon, it points to the time when the sun leaves the dial.

Having thus found all the hour distances from XII, lay them down upon your dial plane, either by dividing a semicircle into two quadrants, or by the line of chords.

In all declining dials, the line on which the gnomon stands makes an angle with the twelve o'clock line, and falls among the forenoon hour lines, if the dial declines towards the east; and among the afternoon hour lines, when the dial declines

declines towards the west ; that is, to the left hand from the twelve o'clock line in the former case, and to the right hand from it in the latter.

To find the distance of this line from that of twelve.

This may be considered, 1. If the dial declines from the south towards the east, then count the degrees of that declination in the horizon, from the east point towards the north, and bring the lower end of the quadrant to that degree of declination where the reckoning ends ; then turn the globe, until the first meridian cuts the horizon in the like number of degrees, counted from the south point towards the east, and the quadrant and first meridian will cross one another at right angles, and the number of degrees of the quadrant, which are intercepted between the first meridian and the zenith, is equal to the distance of this line from the twelve o'clock line.

The numbers of the first meridian, which are intercepted between the quadrant and the north pole, is equal to the elevation of the style above the plane of the dial.

The second case is, when the dial declines westward from the south.

Count the declination from the east point of the horizon, towards the south, and bring the quadrant of altitude to the degree in the horizon, at which the reckoning ends, both for finding the forenoon hours, and the distance of the substile, or gnomon line, from the meridian; and for the afternoon hours, bring the quadrant to the opposite degrees in the horizon, namely, as far from the west towards the north, and then proceed in all respects as before.

It is presumed, that the foregoing instances will be sufficient to illustrate the general principles of dialling, and to give the pupil a general idea of that pleasing science; for accurate and expeditious methods of constructing dials, we must refer him to treatises written expressly on that subject.

N A V I G A T I O N

EXPLAINED BY THE

G L O B E.

NAVIGATION is the art of guiding a ship at sea, from one place to another, in the safest and most convenient manner. In order to attain this, four things are particularly necessary :

1. To know the situation and distance of places.

2. To know at all times the points of the compass.

3. To know the line in which the ship is to be directed from one place to the other.

4. To know, in any part of the voyage, what point of the globe the ship is upon.

The knowledge of the distance and situation of places, between which a voyage is to be made, implies not only a general knowledge of geography, but of several other particulars, as the rocks, sands, straights, rivers, &c. near which we are to sail; the bending out, or running in of the shores, the knowledge of the times that particular winds set in, the seasons when storms and hurricanes are to be expected, but especially the tides; these, and many other similar circumstances, are to be learned from sea charts, journals, &c. but chiefly by observation and experience.

The second particular to be attained, is the knowledge at all times of the points of the compass, where the ship is. The ancients, to whom the polarity of the loadstone was unknown, found in the day-time the east or west, by the rising or setting of the sun; and at night, the north by the polar star. We have the advantage of the mariner's compass, by which, at any time in the wide ocean, and the darkest night, we know
where

where the north is, and consequently the rest of the points of the compass.

Indeed, before the invention of the mariner's compass, the voyages of the Europeans were principally confined to coasting; but this fortunate discovery has enabled the mariner to explore new seas, and discover new countries, which, without this valuable acquisition, would probably have remained for ever unknown.

The third thing required to be known, is the line which a ship describes upon the globe of the earth, in going from one place to another.

The shortest way from one place to another, is an arc of a great circle, drawn through the two places.

The most convenient way for a ship, is that by which we may sail from one place to another, directing the ship all the while towards the same point of the compass.

A ship is guided by steering or directing her towards some points of the compass; the line wherein a ship is directed, is called the ship's
B b 3 course,

course, which is named from the point towards which she sails.

Thus if a ship sails towards the north-east point, her course is said to be N. E.

In long voyages, a ship's way may consist of a great number of different courses, as from A to B, from B to C, and from C to D, fig. 9, plate XII. ; when we speak of a ship's course, we consider one of these at a time ; the seldomer the course is changed, the more easily the ship is directed.

IF TWO PLACES, A AND Z, FIG. 7, PLATE XII. LIE UNDER THE SAME MERIDIAN, the course from the one to the other is due north or south. Thus let A Z be part of a meridian ; if A be south of Z, the course from A to Z must be north, and the course from Z to A south. This is evident from the nature of a meridian, that it marks upon the horizon the north and south points, and that every point of any meridian is north or south from every other point of it. From hence we may deduce the following corollary : that if a ship sails due north or south, she will continue on the same meridian.

IF TWO PLACES LIE UNDER THE EQUATOR, the course from one to the other is an arc of the equator, and is due east or west. Thus let a z, fig. 7, be a part of the equator; if a be west from z, the course from a to z is east, and the course from z to a is west: for since the equator marks the east and west points upon the horizon, every point of the equator lies east or west of every other point of it, as may be seen upon the globe, by placing it as for a right sphere, and bringing a or z, or any of the intermediate points, to the zenith; when it will be evident, that if we are to go from one of these points a, to the other z, or to any point on the equator, we must continue our course due east to arrive at a, or vice versa. From hence we may deduce this consequence, that if a ship under the equator sails due east or west, she will continue under the equator.

In the two foregoing cases, the course being an arc of a great circle, (the meridian or equator) is the shortest and the most convenient way it can sail.

IF TWO PLACES LIE UNDER THE SAME PARALLEL, the course from one to the other is due east or west; this may be seen upon the globe, by the following method: bring any point of a parallel

to the zenith, and stretch a thread over it, perpendicular to the meridian; the thread will then be a tangent to the parallel, and stand east and west from the point of contact. Hence, if a ship sails in any parallel, due east or west, she will continue in the same parallel. In this case, the most convenient course, though not the shortest from one to the other, is to sail due east or west.

IF TWO PLACES LIE NEITHER UNDER THE EQUATOR, NOR ON THE SAME MERIDIAN, NOR IN THE SAME PARALLEL, the most convenient, though not the shortest, course from one to the other, is in a rhumb.

For if we should in this case attempt to go the shortest way, in a great circle drawn through the two places, we must be perpetually changing our course. Thus fig 8, whatever is the bearing of Z from A, the bearings of all the intermediate points, as B, C, D, E, &c. will be different from it, as well as different from each other, as may be easily seen upon the globe, by bringing the first point A to the zenith, and observing the bearing of Z from each of them. Thus suppose when the globe is rectified to the horizon of A, the bearing of Z from A be north-east, and the

the angle of position of Z, with regard to A, be 45 degrees; if we bring B to the zenith, we shall have a different horizon, and the bearing and angle of position from Z to B will be different from the former; and so on of the other points C D E, they will each of them have a different horizon, and Z will have a different bearing and angle of position.

From hence we may draw this corollary, that when two places lie one from the other, towards a point not cardinal, if we sail from one place towards the point of the other's bearing, we shall never arrive at the other place. Thus if Z, lies north-east from A, if we sail from A towards the north-east, we shall never arrive at Z.

A RHUMB upon the globe is a line drawn from a given place A, so as to cut all the meridians it passes through at equal angles; the rhumbs are denominated from the points of the compass, in a different manner from the winds. Thus, at sea, the north-east wind is that which blows from the north-east point of the horizon, towards the ship in which we are; but we are said to sail upon the N. E. rhumb, when we go towards the north-east.

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The rhumb $A B C D Z$, fig. 8, plate XII. passing through the meridians $L M$, $N O$, $P Q$, makes the angles $L A B$, $N B C$, $P C D$, equal; from whence it follows, that the direction of a rhumb is in every part of it towards the same point of the compass; thus from every point of a north-east rhumb upon the globe, the direction is towards the north-east, and that rhumb makes an angle of 45 deg. with every meridian it is drawn through.

Another property of the rhumbs is, that equal parts of the same rhumb are contained between parallels of equal distance of latitude; so that a ship continuing in the same rhumb, will run the same number of miles in sailing from the parallel of 10 to the parallel of 30, as she does in sailing from the parallel of 30 to that of 50.

The fourth thing mentioned to be required in navigation, was, to know at any time what point of the globe a ship is upon. This depends upon four things; 1. the longitude; 2. the latitude; 3. the course the ship has run; 4. the distance, that is, the way she has made, or the number of leagues or miles she has run in that course, from the place of the last observation. Now any two
of

of these being known, the rest may be easily found.

Having thus given some general idea of navigation, we now proceed to the problems by which the cases of sailing are solved on the globe.

P R O B L E M XLIV.

Given the difference of latitude, and difference of longitude, to find the course and distance sailed. *

Example. Admit a ship sails from a port A, in latitude 38 deg. to another port B, in latitude 5 deg. and finds her difference of longitude 43 deg.

Let the port A be brought to the meridian, and elevate the globe to the given latitude of that port 38 deg. and fixing the quadrant of altitude precisely over it on the meridian, move the quadrant to lie over the second port B, (found by the given difference of latitude and longitude) then will it cut in the horizon 50 deg. 45 min. for the angle of the SHIP'S COURSE to be steered from

* See Martin on the Globes.

from the port A. Also, count the degrees in the quadrant between the two ports, which you will find 51 deg.; this number multiplied by 60, (the nautical miles in a degree) will give 3060 for the distance run.

P R O B L E M XLV.

Given the difference of latitude and course, to find the difference of longitude and distance failed.

Example. Admit a ship sails from a port A, in 25 deg. north latitude, to another port B, in 30 deg. south latitude, upon a course of 43 deg.

Bring the port A to the meridian, and rectify the globe to the latitude thereof 25 deg. where fix the quadrant of altitude, and place it so as to make an angle with the meridian of 43 deg. in the horizon, and observe where the edge of the quadrant intersects the parallel of 30 deg. south latitude, for that is the place of the port B. Then count the number of degrees on the edge of the quadrant intersected between the two ports, and there will be found 73 deg. which multiplied by 60, gives 4380 miles for the distance failed. As the two ports are now known, let each be brought

brought to the meridian, and observe their difference of longitude in the equator respectively, which will be found 50 deg.

N. B. Had this problem been solved by LOXODROMICS, or sailing on a rhumb, the difference of longitude would then have been 52 deg. 30 min. between the two ports.

P R O B L E M XLVI.

Given the difference of latitude and distance run, to find the difference of longitude, and angle of the course.

Example. . Admit a ship sails from a port A, in latitude 50 deg. to another port B, in latitude 17 deg. 30 min. and her distance run be 2220 miles. Rectify the globe to the latitude of the place A, then the distance run, reduced to degrees, will make 37 deg. which are to be reckoned from the end of the quadrant lying over the port A, under the meridian; then is the quadrant to be moved, till the 37 deg. coincides with the parallel of 17 deg. 30 min. north latitude, then will the angle of the course appear in the arch of the horizon, intercepted between the quadrant and the meridian, which will be 32 deg.

40 min. ; and by making a mark on the globe for the port B, and bringing the same to the meridian, you will observe what number of degrees pass under the meridian, which will be 20, the difference of longitude required.

P R O B L E M XLVII.

Given the difference of longitude and course, to find the difference of latitude and distance sailed.

Example. Suppose a ship sails from A, in the latitude 51 deg. on a course making an angle with the meridian of 40 deg. till the difference of longitude be found just 20 deg. ; then rectifying the globe to the latitude of the port A, place the quadrant of altitude so as to make an angle of 40 deg. with the meridian ; then observe in what point it intersects the meridian passing through the given longitude of the port B, and there make a mark to represent the said port ; then the number of degrees intercepted between that and the port A will be 28, which will give 1680 miles for the distance run. And the said mark for the port B, being brought to the meridian, will have it's latitude there shewn to be 27 deg. 40 min.

P R O B L E M XLVIII.

Given the course and distance sailed, to find the difference of longitude, and difference of latitude.

Example. Suppose a ship sails 1800 miles from a port A, 51 deg. 15 min. south-west, on an angle of 45 deg. to another port B.

Having rectified the globe to the port A, fix the quadrant of altitude over it in the zenith, and place it to the south-west point in the horizon; then upon the edge of the quadrant under 30 deg. (equal to 1800 miles from the port A) is the port B; which bring to the meridian, and you will there see the latitude; and at the same time, it's longitude in the equator, in the point cut by the meridian.

In all these cases, the ship is supposed to be kept upon the ARCH OF A GREAT CIRCLE, which is not difficult to be done, very nearly, by means of the globe, by frequently observing the latitude, measuring the distance sailed, and (when you can) finding the difference of longitude; for one of these being given, the place and course of
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the ship is known at the same time ; and therefore the preceding course may be altered, and rectified without any trouble, through the whole voyage, as often as such observations can be obtained, or it is found necessary. Now if any of these DATA are but of the quantity of four or five degrees, it will suffice for correcting the ship's course by the globe, and carrying her directly to the intended port, according to the following problem.

P R O B L E M XLIX.

To steer a ship upon the arch of a great circle by the given difference of latitude, or difference of longitude, or distance sailed in a given time.

Admit a ship sails from a port A, to a very distant port Z, whose latitude and longitude are given, as well as it's geographical bearing from A ; then

First, having rectified the globe to the port A, lay the quadrant of altitude over the port Z, and draw thereby the arch of a great circle through A and Z ; this will design the intended path or tract of the ship.

Secondly,

Secondly, having kept the ship upon the first given course for some time, suppose by an observation you find the latitude of the PRESENT PLACE of the ship, this added to, or subducted from the latitude of the port A, will give the present latitude in the meridian; to which bring the path of the ship, and the part therein, which lies under the new latitude, is the true place B of the ship in the great arch. To the latitude of B rectify the globe, and lay the quadrant over Z, and it will shew in the horizon the NEW COURSE to be steered.

Thirdly, suppose the ship to be steered upon this course, till her distance run be found 300 miles, or 5 deg.; then, the globe being rectified to the place B in the zenith, laying the quadrant from thence over the great arch, make a mark at the 5th degree from B, and that will be the present place of the ship, which call C; which being brought to the meridian, it's latitude and longitude will be known. Then rectify the globe to the place C, and laying the quadrant from thence to Z, the new course to be steered will appear in the horizon.

Fourthly, having steered some time upon this new course, suppose, by some means or other,

C c

you

you come to know the difference of longitude of the present place of the ship, and of any of the preceding places, C, B, A; as B, for instance; then bring B to the meridian, and turn the globe about, till so many degrees of the equator pass under the meridian, as are equal to the discovered difference of longitude, then the point of the great arch cut by the meridian, is the present place D of the ship, to which the new course is to be found as before.

And thus, by repeating these observations at proper intervals, you will find future places, E, F, G, &c. in the great arch; and by rectifying the course at each, your ship will be conducted on the great circle, or the nearest way from the port A to Z, by the USE OF THE GLOBE only.

OF THE GENERAL DISTRIBUTION OF LAND AND WATER IN THE TERRAQUEOUS GLOBE, WITH SOME OTHER GEOGRAPHICAL OBSERVATIONS.

Though the nature of our plan does not permit us to enter into many geographical disquisitions, yet we presume the following general view will not be deemed irrelative to the subject; as while it tends to bring the pupil acquainted with the grand outline of the globe, it will be a pleasing relief from the more abstruse part in which he has been exercised.

If the pupil considers the terrestrial globe as a map, he will find that land and water are generally contrasted to one another on the opposite side of the world; that is, if there be land on one side, it is answered by water in the antipodes. Thus for instance, the circumpolar parts of the northern hemisphere consist chiefly of land; but the circumpolar parts of the south consist almost entirely of water. It was formerly thought, that as there is so much land about the north pole, land would also have been found about the south pole, to have ballanced it. * But the discoveries of our circumnavigators have shewn, that no such land is to be met with; nor ought it

C c 2

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* Jones's Physiological Disquisitions.

to have been expected, for land on one side is ballanced by water on the opposite.

If you bring the Cape of Good Hope under the strong brazen meridian, this meridian will pass through the heart of the continents of Europe and Africa; but the opposite semicircle passes through the middle of the great south sea. When the middle of the northern continent of America, about the meridian of Mexico, is examined in the same way, the opposite part passes through the middle of the Indian ocean. The southern continent of New Holland is opposite to the Atlantic ocean. This alternation of land and water is too regular to have been casual; but of the reason for it, or the benefits arising from it, we are altogether ignorant.

There is another phaenomenon which is more level to our capacity, the manifest superiority of the northern hemisphere of the world over the southern. It has more land, more sun, more light, more heat, more arts, more sense, more learning, more truth, more religion. The land of the southern hemisphere, that is, the land which lies on the other side of the equinoctial line, does not amount to one-fourth part of what is found on the northern side.

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The sun, from the eccentricity of the earth's orbit, and the situation of the aphelion, makes our summer eight days longer than the summer of the other hemisphere, which in the space of 4000 years amounts to more than 87 years.

The temperature of the earth and atmosphere in the higher northern latitudes, is much more mild and moderate than in the correspondent southern latitudes. The dreary face of Staten land, with the weather-beaten Cape of South America, a climate so severe, as scarcely to admit of any human inhabitant, is not nearer to the pole than the northern counties of England, while the difference in the atmosphere and the aspect of the earth is almost incredible.

The nights of the northern hemisphere display a richer canopy than those of the southern. The stars of superior magnitude are more numerous on this side the equinoctial than on the other. When the sun is remote from us in winter, our longest nights are illuminated by the principal stars of the firmament. When the sun enters Capricorn, the whole constellation of Orion, the brightest in the heavens, comes to the meridian about midnight, with several other stars of the first magnitude. If the midwinter of the south-

ern hemisphere be compared, the inferiority of the nocturnal illumination is wonderful, and will be evident to any one who examines the problem on a celestial globe.

The intellectual advantages of the northern hemisphere are equally conspicuous with the natural advantages. In the one, the arts and sciences have always flourished; but where are the poets, the historians, the orators, the philosophers, of the southern world? We may as well search for the sciences among the beasts of the wilderness. There would be no end, if we were to continue the comparison through all the several improvements which may be comprehended under the name of humanity; for here we have every thing that can adorn human life, and there they can have nothing. He that considers the subject, will find that the natural and intellectual advantages always correspond to each other.

Every habitable latitude enjoys a heat of 60 degrees at least, for two months; which heat seems necessary for the growth and maturity of corn. The quickness of vegetation in the higher latitudes, proceeds from the duration of the sun over the horizon. Rain is little wanted, as the
earth

earth is sufficiently moistened by the melting of the snow that covers it during the winter: circumstances, which, among many others, evince the wise disposition of things by divine providence.

It is owing to the same provident hand that the globe of the earth is intersected with seas and mountains, in a manner that on it's first appearance seems altogether irregular and fortuitous, presenting to the uninformed eye the view of an immense ruin; but when the effects of these seeming irregularities on the face of the globe, are carefully inspected, they are found most beneficial, and even necessary to the welfare of it's inhabitants; for to say nothing of the advantages of trade and commerce, which could not exist without these seas, it is by them that the cold of the higher, and the heat of the lower latitude, is moderated. It is by the want of seas, that the interior parts of Asia, as Siberia and Great Tartary, as well as those of Africa, are rendered almost uninhabitable. In the same manner, mountains are necessary, not only as the sources of rivers, but as a defence against heat, in the warm latitudes; without the Alps, Pyrencees, Apenine, the mountains Dauphine and Auvergne, Italy, Spain, and France, would be deprived of

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the

the mild air they now enjoy. Without the Balgate hills, or Indian Apenine, India would have been a desert. Hence Jamaica, St. Domingo, Sumatra, and most other intertropical islands, are furnished with mountains, from which proceed the breezes by which they are refreshed.*

* Kirwan on Climates.



ESSAY II.

PART IV.

E S S A Y II.

P A R T IV.

OF THE USE OF THE CELESTIAL GLOBE.

THE celestial globe is an artificial representation of the heavens, having the fixed stars drawn upon it, in their natural order and situation.

It is not to be supposed that the celestial globe is so just a representation of the heavens as the terrestrial globe is of the earth ; because here the stars are drawn upon a convex surface, whereas they naturally appear in a concave one. But suppose the globe were made of glass, then to an eye placed in the center, the stars which are drawn upon it would appear in a concave surface, just as they do in the heavens.

Or

Or if the reader was to suppose that holes were made in each star, and an eye placed in the center of the globe, it would view, through those holes, the same stars in the heavens that they represent.

As the terrestrial globe, by turning on it's axis, represents the real diurnal motion of the earth; so the celestial globe, by turning on it's axis, represents the apparent diurnal motion of the heavens.

For the sake of perspicuity, and to avoid continual references, it will be necessary to repeat here some articles which have been already mentioned.

The ecliptic is that graduated circle which crosses the equator in an angle of about $23\frac{1}{2}$ degrees, and the angle is called the obliquity of the ecliptic.

The circle is divided into twelve equal parts, consisting of 30 degrees each; the beginnings of them are marked with characters, representing the twelve signs.

Aries Υ , Taurus $\var�$, Gemini Π , Cancer $\♋$,
 Leo Ω , Virgo $\♍$, Libra $\♎$, Scorpio $\♏$,
 Sagittarius $\♐$, Capricornus $\♑$, Aquarius $\♒$,
 Pisces $\♓$.

Upon my father's globes, just under the ecliptic, the months, and days of each month, are graduated, for the reader fixing the artificial sun upon it's place in the ecliptic.

The two points where the ecliptic crosses the equinoctial, (the circle that answers to the equator on the terrestrial globe) are called the equinoctial points; they are at the beginnings of Aries and Libra, and are so called, because when the sun is in either of them, the day and night is every where equal.

The first points of Cancer and Capricorn are called solstitial points; because when the sun arrives at either of them, he seems to stand in a manner still for several days; in respect to his distance from the equinoctial, when he is in one solstitial point, he makes to us the longest day; when in the other, the longest night.

The latitude and longitude of stars are determined from the ecliptic.

The longitude of the stars and planets is reckoned upon the ecliptic ; the numbers beginning at the first points of Aries γ , where the ecliptic crosses the equator, and increasing according to the order of the signs.

Thus suppose the sun to be in the 10th degree of Leo, we say, his longitude, or place, is four signs, ten degrees ; because he has already passed the four signs, Aries, Taurus, Gemini, Cancer, and is ten degrees in the fifth.

The latitude of the stars and planets is determined by their distance from the ecliptic upon a secondary or great circle passing through it's poles, and crossing it at right angles.

Twenty-four of these circular lines, which cross the ecliptic at right angles, being fifteen degrees from each other, are drawn upon the surface of our celestial globe ; which being produced both ways, those on one side meet in a point on the northern polar circle, and those on the other meet in a point on the southern polar circle.

The

The points determined by the meeting of these circles are called the poles of the ecliptic, one north, the other south.

From these definitions it follows, that longitude and latitude on the celestial globe bears just the same relation to the ecliptic, as they do on the terrestrial globe to the equator.

Thus as the longitude of places on the earth is measured by degrees upon the equator, counting from the first meridian; so the longitude of the heavenly bodies is measured by degrees upon the ecliptic, counting from the first point of Aries.

And as latitude on the earth is measured by degrees upon the meridian, counting from the equator; so the latitude of the heavenly bodies is measured by degrees upon a circle of longitude, counting either north or south from the ecliptic.

The sun, therefore, has no latitude, being always in the ecliptic; nor do we usually speak of his longitude, but rather of his place in the ecliptic, expressing it by such a degree and minute of such a sign, as 5 degrees of Taurus, instead of 35 degrees of longitude.

The distance of any heavenly body from the equinoctial, measured upon the meridian, is called it's declination.

Therefore, the sun's declination, north or south, at any time, is the same as the latitude of the place to which he is then vertical, which is never more than $23\frac{1}{2}$ degrees.

Therefore all PARALLELS OF DECLINATION on the celestial globe are the very same as parallels of latitude on the terrestrial.

Stars may have north latitude and south declination, and vice versa.

That which is called longitude on the terrestrial globe, is called RIGHT ASCENSION on the celestial; namely, the sun or stars distance from that meridian which passes through the first point of Aries, counted on the equinoctial.

Astronomers also speak of OBLIQUE ASCENSION and DESCENSION, by which they mean the distance of that point of the equinoctial from the first point of Aries, which in an oblique sphere rises or sets, at the same time that the sun or star rises or sets.

ASCEN-

ASCENSIONAL difference is the difference betwixt right and oblique ascension. The sun's ascensional difference turned into time, is just so much as he rises before or after six o'clock.

The celestial signs and constellations on the surface of the celestial globe, are represented by a variety of human and other figures, to which the stars that are either in or near them, are referred.

The several systems of stars which are applied to those images, are called constellations. Twelve of these are represented on the ecliptic circle, and extend both northward and southward from it. So many of those stars as fall within the limits of 8 degrees on both sides of the ecliptic circle, together with such parts of their images as are contained within the aforesaid bounds, constitute a kind of broad hoop, belt, or girdle, which is called the ZODIAC.

The names and the respective characters of the twelve signs of the ecliptic may be learned by inspection on the surface of the broad paper circle, and the constellations from the globe itself.

The zodiac is represented by eight circles parallel to the ecliptic, on each side thereof; these circles are one degree distant from each other, so that the whole breadth of the zodiac is 16 degrees.

Amongst these parallels, the latitude of the planets is reckoned; and in their apparent motion they never exceed the limits of the zodiac.

On each side of the zodiac, as was observed, other constellations are distinguished; those on the north side are called northern, and those on the south side of it, southern constellations.

All the stars which compose these constellations, are supposed to increase their longitude continually; upon which supposition, the whole starry firmament has a slow motion from west to east; insomuch that the first star in the constellation of Aries, which appeared in the vernal intersection of the equator and ecliptic in the time of Meton the Athenian, upwards of 1900 years ago, is now removed about 30 degrees from it.

TO REPRESENT THE MOTION OF THE EQUINOCTIAL POINTS BACKWARDS, OR IN ANTECEDENTIA, UPON THE CELESTIAL GLOBE, elevate the north pole, so that it's axis may be perpendicular to the plane of the broad paper circle, and the equator will then be in the same plane; let these represent the ecliptic, and then the poles of the globe will also represent those of the ecliptic; the ecliptic line upon the globe will at the same time represent the equator, inclined in an angle of $23\frac{1}{2}$ degrees to the broad paper circle, now called the ecliptic, and cutting it in two points, which are called the equinoctial intersections.

Now if you turn the globe slowly round upon it's axis from east to west, while it is in this position, these points of intersection will move round the same way; and the inclination of the circle, which in shewing this motion represents the equinoctial, will not be altered by such a revolution of the intersecting or equinoctial points. This motion is called the precession of the equinoxes, because it carries the equinoctial points backwards amongst the fixed stars.

The poles of the world seem to describe a circle from east to west, round the poles of the ecliptic, arising from the precession of the

equinox. It is a very slow motion, for the equinoctial points take up 72 years to move one degree, and therefore they are 25,920 years in describing 360 degrees, or completing a revolution.

This motion of the poles is easily represented by the above-described position of the globe, in which, if the reader remembers, the broad paper circle represents the ecliptic, and the axis of the globe being perpendicular thereto, represents the axis of the ecliptic; and the two points, where the circular lines meet, will now represent the poles of the world, whence as the globe is slowly turned from east to west, these points will revolve the same way about the poles of the globe, which are here supposed to represent the poles of the ecliptic. The axis of the world may revolve as above, although its situation, with respect to the ecliptic, be not altered; for the points here supposed to represent the poles of the world, will always keep the same distance from the broad paper circle, which represents the ecliptic in this situation of the globe.*

From

* Rutherford's System of Nat. Philos. vol. ii. p. 730.

From the different degrees of brightness in the stars, some appear to be greater than others, or nearer to us; on our celestial globe they are distinguished into seven different magnitudes.

O F T H E

USE OF THE CELESTIAL GLOBE,

IN THE SOLUTION OF

PROBLEMS RELATIVE TO THE SUN.

EVERY thing that relates to the sun is of such importance to man, that in all things he claims a natural preheminance. The sun is at once the most beautiful emblem of the Supreme Being, and, under his influence, the fostering parent of worlds ; being present to them by his rays, cheering them by his countenance, cherishing them by his heat, adorning them at each returning spring with the gayest and richest attire, illuminating them with his light, and feeding the lamp of life.

To

To the ancients he was known under a variety of names, each characteristic of his different effects; he was their Hercules, the great deliverer, the restorer of light out of darkness, the dispenser of good, continually labouring for the happiness of a depraved race. He was the Mithra of the Persians, a word derived from love, or mercy, because the whole world is cherished by him, and feels as it were the effects of his love.

In the sacred scriptures, the original source of all emblematical writings, our Lord is called our sun, and the sun of righteousness; and as there is but one sun in the heavens, so there is but one true God, the maker and redeemer of all things, the light of the understanding, and the life of the soul.

As in scripture our God is spoke of as a shield and buckler, so the sun is characterized by this mark ☉ representing a shield or buckler, the middle point the umbo, or boss; for it is love, or life, which alone can protect from fear and death.

His celestial rays, like those of the sun, take their circuit round the earth; there is no corner

of it so remote as to be without the reach of their vivifying and penetrating power. As the material light is always ready to run it's heavenly race, and daily issues forth with renewed vigour, like an invincible champion, still fresh to labour; so likewise did our REDEEMING GOD rejoice to run his glorious race, he excelled in strength, and triumphed, and continues to triumph over all the powers of darkness, and his ever manifesting himself as the deliverer, the protector, the friend, and father of the human race, *

P R O B L E M L.

To rectify the celestial globe.

To rectify the celestial globe, is to put it in that position in which it may represent exactly the apparent motion of the heavens.

In different places, that position will vary, and that according to the different latitude of the places.

Therefore, to rectify for any place, find first, by the terrestrial globe, the latitude of that place.

The

* Horne on the Psalms.

The latitude of the place being found in degrees, elevate the pole of the celestial globe the same number of degrees and minutes above the plane of the horizon, for this is the name given to the broad paper circle, in the use of the celestial globe.

Thus the latitude of London being $51\frac{1}{2}$ degrees, let the globe be moved till the plane of the horizon cuts the meridian in that point.

The next rectification is for the sun's place, which may be performed as directed in pr. xxix; or look for the day of the month close under the ecliptic line, against which is the sun's place, place the artificial sun over that point, then bring the sun's place to the graduated edge of the strong brazen meridian, and set the hour index to the most elevated twelve.

Thus on the 24th of May the sun is in $3\frac{1}{2}$ degrees of Gemini, and is situated near the bull's eye and the seven stars which are not then visible, on account of his superior light. If the sun were on that day to suffer a total eclipse, these stars would then be seen shining with their accustomed brightness.

Lastly,

Laſtly, ſet the meridian of the globe north and ſouth, by the compaſs.

And the globe will be rectified, or put into a ſimilar poſition, to the concave ſurface of the heavens, for the given latitude.

P R O B L E M L I.

To find the declination of the ſun for any given day in the year.

Seek the day of the month cloſe under the ecliptic line, againſt which is the ſun's place; bring that point under the ſtrong braſs meridian, and the degree that ſtands over it is the ſun's declination for that day.

Thus on the 23d of May the ſun's declination will be about 23 deg. 10 min.; and upon the 23d of Auguſt it will be 11 deg. 13 min.

P R O B L E M L I I .

To find the sun's right ascension.

The right ascension of the sun, &c. is an arch of the equinoctial contained between the beginning of Aries, and that point of it which comes to the meridian with it.

Therefore, bring the sun's place to the meridian, and that point of the equinoctial which is under the meridian will shew the sun's right ascension.

Thus on the 11th of May the right ascension will be found to be 47 deg. 10 min.

By the two last problems, we see that the right ascension and declination is found after the same manner as the longitude and latitude of a place upon the terrestrial globe.

Bring the sun's place to the western edge of the horizon, and the degree of the equator, cut by the horizon, is his oblique descension; carry him round to the eastern side, and you will there find his oblique ascension.

P R O B L E M L I I I .

The latitude of the place and the sun's place being given, to find the sun's amplitude.

That degree from the east or west in the horizon, wherein any object rises or sets, is called the **AMPLITUDE**.

Rectify the globe to the latitude of the place, and bring the sun's place to the eastern side of the meridian, and the arch of the horizon intercepted between that point and the eastern point, will be the sun's amplitude at rising.

If the same point be brought to the western side of the horizon, the arch of the horizon intercepted between that point and the western point, will be the sun's amplitude at setting.

Thus on the 24th of May the sun rises at four, with 36 degrees of eastern amplitude, that is, 36 degrees from the east towards the north, and sets at eight, with 36 degrees of western amplitude.

The amplitude of the sun at rising and setting increases with the latitude of the place; and in very high northern latitudes, the sun scarce sets
before

before he rises again. Homer had heard something of this, though it is not true of the Læstrygonæ, to whom he applies it.

Six days and nights a doubtful course we steer ; }
 The next, proud LAMOS' lofty towers appear, }
 And Læstrygonia's gates arise distinct in air. }
 The shepherd quitting here at night the plain,
 Calls, to succeed his cares, the watchful swain.
 But he that scorns the chains of sleep to wear,
 And adds the herdsman's to the shepherd's care,
 So near the pastures, and so short the way, }
 His double toils may claim a double pay, }
 And join the labours of the night and day. }

P R O B L E M L I V .

To find the sun's altitude at any given time of the day.

Set the center of the artificial sun to his place in the ecliptic upon the globe, and rectify it to the latitude and zenith ; bring the center of the artificial sun under the strong brass meridian, and set the hour index to that XII which is most elevated ; turn the globe to the given hour, and move the graduated edge of the quadrant to the center of the artificial sun ; and that degree on the quadrant which

which is cut by the sun's center, is the sun's height at that time.

The artificial sun being brought under the strong brass meridian, and the quadrant laid upon it's center, will shew it's meridian, or greatest altitude, for that day.

If the sun be in the equator, his greatest or meridian altitude is equal to the elevation of the equator, which is always equal to the co-latitude of the place.

Thus on May 24, at nine o'clock, the sun has about 44 degrees of altitude; and at six in the evening of the same day, his altitude will be about 20 degrees.

OF THE AZIMUTHAL, OR VERTICAL CIRCLES.

The vertical point, that is, the uppermost point of the celestial globe, represents a point in the heavens, directly over our heads, which is called our zenith.

From this point circular lines may be conceived crossing the horizon at right angles.

These

These are called **AZIMUTH** or **VERTICAL CIRCLES**. That one which crosses the horizon at 10 deg. distance from the meridian on either side, is called an azimuth circle of 10 deg.; that which crosses at 20, is called an azimuth of 20 deg.

The azimuth of 90 deg. is called the **PRIME VERTICAL**: it crosses the horizon at the eastern and western points.

Any **AZIMUTH CIRCLE** may be represented by the graduated edge of the brass quadrant of altitude, when the center upon which it turns is screwed to that point of the strong brass meridian which answers to the latitude of the place, and the place is brought into the zenith. See prob. xxx.

If the said graduated edge should lie over the sun's center or place, at any given time, it will represent the sun's azimuth at that time.

If the graduated edge be fixed at any point, so as to represent any particular azimuth, and the sun's place be brought there, the horary index will shew at what time of that day the sun will be in that particular azimuth.

Here

Here it may be observed, that the AMPLITUDE and azimuth are much the same.

The amplitude shewing the bearing of any object WHEN IT RISES OR SETS, from the EAST and WEST points of the horizon.

The azimuth the bearing of any object when it IS ABOVE THE HORIZON, either from the NORTH OR SOUTH points thereof. These descriptions and illustrations being understood, we may proceed to

P R O B L E M LV.

The latitude, the sun's place, and his altitude, being given; to find the hour of the day, and the sun's azimuth from the meridian.

Having rectified the globe for the latitude, the zenith, and the sun's place, turn the globe and the quadrant of altitude, so that the sun's place may cut the given degree of altitude: then the index will shew the hour, and the quadrant will cut the azimuth in the horizon. Thus, if at London, on the 21st of August, the sun's altitude be 36 deg. in the forenoon, the hour of the day will

will be IX, and the sun's azimuth about 58 deg. from the south part of the meridian.

P R O B L E M LVI.

The latitude, hour of the day, and the sun's place being given, to find the sun's altitude and azimuth.

Rectify the globe for the latitude, the zenith, and the sun's place, then the number of degrees contained betwixt the sun's place and the vertex, is the sun's meridional zenith distance; the complement of which to 90 deg. is the sun's meridian altitude. If you turn the globe about until the index points to any other given hour, then bringing the quadrant of altitude to cut the sun's place, you will have the sun's altitude at that hour; and where the quadrant cuts the horizon, is the sun's azimuth at the same time. Thus May the 1st at London, the sun's meridian altitude will be $53\frac{1}{2}$ deg.; and at 10 o'clock in the morning, the sun's altitude will be 46 deg. and his azimuth about 46 deg. from the south part of the meridian.

P R O B L E M LVII.

The latitude of the place, and the day of the month being given; to find the depression of the sun below the horizon, and the azimuth at any hour of the night.

Having rectified the globe for the latitude, the zenith, and the sun's place, take a point in the ecliptic exactly opposite to the sun's place, and find the sun's altitude and azimuth, as by the last problem, and these will be the depression and the altitude required.

Thus if the time given be the 1st of November, at 10 o'clock at night, the depression and azimuth will be the same as was found in the last problem.

P R O B L E M LVIII.

The latitude, the sun's place, and his azimuth being given, to find his altitude, and the hour.

Rectify the globe for the latitude, the zenith, and the sun's place; then put the quadrant of altitude to the sun's azimuth in the horizon, and turn the globe till the sun's place meets the edge

of the quadrant, then the said edge will shew the altitude, and the index point to the hour.

Thus, May 21st, at London, when the sun is due east, his altitude will be about 24 degrees, and the hour about VII in the morning; and when his azimuth is 60 degrees south-westerly, the altitude will be about $44\frac{1}{2}$ degrees, and the hour about $2\frac{3}{4}$ in the afternoon.

Thus the latitude and the day being known, and having besides either the altitude, the azimuth, or the hour, the other two may be easily found.

PROBLEM LIX.

The latitude, the sun's altitude, and his azimuth being given, to find his place in the ecliptic, and the hour.

Rectify the globe for the latitude and zenith, and set the edge of the quadrant to the given azimuth; then turning the globe about, that point of the ecliptic which cuts the altitude, will be the sun's place. Keep the quadrant of altitude in the same position, and having brought the sun's place to the meridian, and the hour in-

dex to 12 at noon, turn the globe about till the sun's place cuts the quadrant of altitude, and then the index will point the hour of the day.

P R O B L E M LX.

The declination and meridian altitude of the sun, or of any star being given, to find the latitude of the place.

Mark the point of declination upon the meridian, according as it is either north or south from the equator ; then slide the meridian up or down in the notches, till the point of declination be so far distant from the horizon, as is the given meridian altitude ; that elevation of the pole will be the latitude.

Thus if the sun's, or any star's meridian altitude be 50 degrees, and it's declination be $11\frac{1}{2}$ degrees north, the latitude will be $51\frac{1}{2}$ degrees north.

PROBLEM LXI.

To find the length of any day in the year, in any latitude, not exceeding $66\frac{1}{2}$ degrees.

Elevate the celestial globe to the latitude, and set the center of the artificial sun to his place upon the ecliptic line on the globe for the given day, and bring it's center to the strong brass meridian, placing the horary index to that XII which is most elevated; then turn the globe till the artificial sun cuts the eastern edge of the horizon, and the horary index will shew the time of sun-rising; turn it to the western side, and you obtain the hour of sun-setting.

The length of the day and night will be obtained, by doubling the time of sun-rising and setting, as before.

PROBLEM LXII.

To find the length of the longest and shortest days in any latitude that does not exceed $66\frac{1}{2}$ degrees.

Elevate the globe according to the latitude, and place the center of the artificial sun for the

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longest

longest day upon the first point of Cancer, but for the shortest day on the first point of Capricorn, then proceed as in the last problem.

But if the place hath south latitude, the sun is in the first point of Capricorn on their longest day, and in the first point of Cancer on their shortest day.

P R O B L E M L X I I I .

To find the latitude of a place, in which it's longest day may be of any given length between twelve and twenty-four hours.

Set the artificial sun to the first point of Cancer; bring it's center to the strong brass meridian, and set the horary index to XII; turn the globe till it points to half the number of the given hours and minutes; then elevate or depress the pole, till the artificial sun coincides with the horizon, and that elevation of the pole is the latitude required.

P R O B L E M LXIV.

To find the time of the sun's rising and setting, the length of day and night, on any place whose latitude lies between the polar circles; and also the length of the shortest day in any of those latitudes, and in what climate they are.

Rectify the globe to the latitude of the given place, and bring the artificial sun to his place in the ecliptic for the given day of the month; and then bring it's center under the strong brass meridian, and set the horary index to that XII which is most elevated.

Then bring the center of the artificial sun to the eastern part of the broad paper circle, which in this case represents the horizon, and the horary index shews the time of the sun-rising; turn the artificial sun to the western side, and the horary index will shew the time of the sun-setting.

Double the time of sun-rising is the length of the night, and the double of that of sun-setting is the length of the day.

Thus on the 5th day of June, the sun rises at 3 h. 40 min. and sets at 8 h. 20 min.; by

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doubling

doubling each number it will appear, that the length of this day is 16 h. 40 min. and that of the night 7 h. 20 min.

The longest day at all places in north latitude, is when the sun is in the first point of Cancer. And,

The longest day to those in south latitude, is when the sun is in the first point of Capricorn.

Wherefore, the globe being rectified as above, and the artificial sun placed to the first point of Cancer, and brought to the eastern edge of the broad paper circle, and the horary index being set to that XII which is most elevated, on turning the globe from east to west, until the artificial sun coincides with the western edge, the number of hours counted, which are passed over by the horary index, is the length of the longest day; their complement to twenty-four hours gives the length of the shortest night.

If twelve hours be subtracted from the length of the longest day, and the remaining hours doubled, you obtain the climate mentioned by ancient historians: and if you take half the climate, and add thereto twelve hours, you obtain
the

the length of the longest day in that climate; this holds good for every climate between the polar circles.

A climate is a space upon the surface of the earth, contained between two parallels of latitude, so far distant from each other, that the longest day in one, differs half an hour from the longest day in the other parallel.

P R O B L E M L X V .

The latitude of a place being given in one of the polar circles, (suppose the northern) to find what number of days (of 24 hours each) the sun doth constantly shine upon the same, how long he is absent, and also the first and last day of his appearance,

Having rectified the globe according to the latitude, turn it about until some point in the first quadrant of the ecliptic (because the latitude is north) intersects the meridian in the north point of the horizon; and right against that point of the ecliptic, on the horizon, stands the day of the month when the longest day begins.

And

And if the globe be turned about till some point in the second quadrant of the ecliptic cuts the meridian in the same point of the horizon, it will shew the sun's place when the longest day ends, whence the day of the month may be found, as before; then the number of natural days contained between the times the longest day begins and ends, is the length of the longest day required.

Again, turn the globe about, until some point in the third quadrant of the ecliptic cuts the meridian in the south part of the horizon; that point of the ecliptic will give the time when the longest night begins.

Lastly, turn the globe about, until some point in the fourth quadrant of the ecliptic cuts the meridian in the south point of the horizon; and that point of the ecliptic will be the place of the sun when the longest night ends.

Or, the time when the longest day or night begins, being known, their end may be found by counting the number of days from that time to the succeeding solstice; then counting the same number of days from the solstitial day, will give the time when it ends.

Or

OF THE EQUATION OF TIME.

It is not possible in a treatise of this kind to enter into a disquisition of the nature of time. It is sufficient to observe, that if we would with exactness estimate the quantity of any portion of infinite duration, or convey an idea of the same to others, we make use of such known measures as have been originally borrowed from the motions of the heavenly bodies. It is true, none of these motions are exactly equal and uniform, but are subject to some small irregularities, which, though of no consequence in the affairs of civil life, must be taken into the account; in astronomical calculation, there are other irregularities of more importance, one of which is the inequality of the natural day.

It is a consideration that cannot be reflected upon without surprize, that wherever we look for commensurabilities and equalities in nature, we are always disappointed. The earth is spherical, but not perfectly so; the summer is unequal, when compared with the winter; the ecliptic disagrees with the equator, and never cuts it twice in the same equinoctial point. The orbit of the earth has an eccentricity more than double in proportion to the spheroidity of it's globe: no
number

number of the revolutions of the moon coincide with any number of the revolutions of the earth in it's orbit: no two of the planets measure one another: and thus it is wherever we turn our thoughts, so different are the views of the Creator from our narrow conception of things; where we look for commensuration, we find variety and infinity.

Thus ancient astronomers looked upon the motion of the sun to be sufficiently regular for the mensuration of time; but by the accurate observations of later astronomers, it is found that neither the days, nor even the hours, as measured by the sun's apparent motion, are of an equal length on two accounts.

1st, A natural or solar day of 24 hours, is that space of time the sun takes up in passing from any particular meridian to the same again; and one revolution of the earth, with respect to a fixed star, is performed in 23 hours, 56 minutes, 4 seconds; therefore, the unequal progression of the earth through her elliptical orbit, (as she takes almost eight days more to run through the northern half of the ecliptic, than she does to pass through the southern) is the reason that the length of the day is not exactly equal to the time in
which

which the earth performs it's rotation about it's axis.

2dly, From the obliquity of the ecliptic to the equator, on which last we measure time ; and as equal portions of one do not correspond to equal portions of the other, the apparent motion of the sun would not be uniform ; or, in other words, those points of the equator which come to the meridian, with the place of the sun on different days, would not be at equal distances from each other.

PROBLEM LXVI.

To illustrate, by the globe, the causes of the equation of time.

This last is easily seen upon the globe, by bringing every tenth degree of the ecliptic to the graduated side of the strong brass meridian, and you will find that each tenth degree on the equator will not come thither with it, but in the following order from γ to ϖ , every tenth degree of the ecliptic comes sooner to the strong brass meridian than their corresponding 10ths on the equator ; those in the second quadrant of the ecliptic, from ϖ to \cap , come later, from \cap to φ sooner, and from φ to Aries later, whilst those

at the beginning of each quadrant come to the meridian at the same time ; therefore the sun and clock would be equal at these four times, if the sun was not longer in passing through one-half of the ecliptic than the other, and the two inequalities joined together, compose that difference which is called the equation of time.

These causes are independent of each other, sometimes they agree, and at other times are contrary to one another.

The inequality of the natural day is the cause that clocks or watches are sometimes before, sometimes behind the sun.

A good and well-regulated clock goes uniformly on throughout the year, so as to mark the equal hours of a natural day, of a mean length : a sundial marks the hours of every day in such a manner, that every hour is a 24th part of the time between the noon of that day, and the noon of the day immediately following. The time measured by a clock is called equal or true time, that measured by the sun-dial apparent time.

OF THE USE OF THE CELESTIAL GLOBE, IN
PROBLEMS RELATIVE TO THE PLANETS.

The situation of the fixed stars being always the same with respect to one another, they have their proper places assigned to them on the globe.

But to the planets no certain place can be assigned, their situation always varying.

That space in the heavens, within the compass of which the planets appear, is called the zodiac.

The latitude of the planets scarce ever exceeding 8 degrees, the zodiac is said to reach about 8 degrees on each side of the ecliptic.

Upon the celestial globe, on each side of the ecliptic, are drawn eight parallel circles, at the distance of one degree from each other, including a space of 16 degrees; these are crossed at right angles, with segments of great circles at every 5th degree of the ecliptic; by these, the place of a planet on the globe, on any given day, may be ascertained with accuracy.

P R O B L E M L X V I I,

To find the place of any planet upon the globe, and by that means to find it's place in the heavens; also, to find at what hour any planet will rise or set, or be on the meridian, on any day in the year.

Rectify the globe to the latitude and sun's place, then find the planet's longitude and latitude in an ephemeris, and set the graduated edge of the moveable meridian to the given longitude in the ecliptic, and counting so many degrees amongst the parallels in the zodiac, either above or below the ecliptic, as her latitude is north or south; and set the center artificial sun to that point, and the center will represent the place of the planet for that time.

Or fix the quadrant of altitude over the pole of the ecliptic, and holding the globe fast, bring the edge of the quadrant to cut the given degree of longitude on the ecliptic; then seek the given latitude on the quadrant, and the place under it is the point sought.

While

While the globe moves about it's axis, this point moving along with it will represent the planet's motion in the heavens. If the planet be brought to the eastern side of the horizon, the horary index will shew the time of it's rising. If the artificial sun is above the horizon, the planet will not be visible: when the planet is under the strong brazen meridian, the hour index shews the time it will be on that circle in the heavens: when it is at the western edge, the time of it's setting will be obtained.

PROBLEM LXVIII.

To find directly the planets which are above the horizon at sun-set, upon any given day and latitude.

Find the sun's place for the given day, bring it to the meridian, set the hour index to XII, and elevate the pole for the given latitude: then bring the place of the sun to the western semi-circle of the horizon, and observe what signs are in that part of the ecliptic above the horizon, then cast your eye upon the ephemeris for that month, and you will at once see what planets possess any of those elevated signs; for such will

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be visible, and fit for observation on the night of that day.

P R O B L E M L X I X .

To find the right ascension, declination, amplitude, azimuth, altitude, hour of the night, &c. of any given planet, for a day of a month and latitude given.

Rectify the globe for the given latitude and day of the month; then find the planet's place, as before directed, and then the right ascension, declination, amplitude, azimuth, altitude, hour, &c. are all found, as directed in the problems for the sun; there being no difference in the process, no repetition can be necessary.

OF THE USE OF THE CELESTIAL GLOBE, IN
PROBLEMS RELATIVE TO THE MOON.

From the sun and planets we now proceed to those problems that concern the moon, the brilliant satellite of our earth, which every month enriches it with it's presence ; by the mildness of it's light softening the darkness of night ; by it's influence affecting the tide ; and by the variety of it's aspects, offering to our view some very remarkable phænomena.

As the orbit of the moon is constantly varying in it's position, and the place of the node always changing, as her motion is even variable in every part of her orbit, the solution of the problems which relate to her, are not altogether so simple as those which concern the sun.

The moon increases her longitude in the ecliptic every day, about 13 degrees, 10 minutes, by which means she crosses the meridian of any place about 50 minutes later than she did the preceding day.

Thus if on any day at noon her place (longitude) be in the 12th degree of Taurus, it will

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be 13 deg. 10 min. more, or 25 deg. 10 min. in Taurus on the succeeding noon.

It is new moon when the sun and moon have the same longitude, or are in or near the same point of the ecliptic.

When they have opposite longitudes, or are in opposite points of the ecliptic, it is full moon.

To ascertain the moon's place with accuracy, we must recur to an ephemeris; but as even in most ephemerides the moon's place is only shewn at the beginning of each day, or XII o'clock at noon, it becomes necessary to supply by a table this deficiency, and assign thereby her place for any intermediate time.

In the nautical ephemeris, published under the authority of the Board of Longitude, we have the moon's place for noon and midnight, with rules for accurately obtaining any intermediate time; but as this ephemeris may not always be at hand, we shall insert, from Mr. Martin's treatise on the globes, a table for finding the hourly motion of the moon. In order, however, to use this table, it will be necessary first to

FIND THE QUANTITY OF THE MOON'S DIURNAL

MOTION

MOTION IN THE ECLIPTIC, for any given day; for the quantity of the moon's diurnal motion varies from about 11 deg. 46 min. the least, to 15 deg. 16 min. when greatest.

The following tables are calculated from the least of 11 deg. 46 min. to the greatest of 15 deg. 16 min. every column being increasing 10 minutes; upon the top of the column is the quantity of the diurnal motion, and on the side of the table are the 24 hours, by which means it will be easy to find what part of the diurnal motion of the moon answers to any given number of hours.

Thus suppose the diurnal motion to be 12 32, look on the top column for the number nearest to it, which you will find to be 12 36, in the sixth column; and under it, against 9 hours, you will find 4 deg. 43 min. which is her motion in the ecliptic in the space of 9 hours for that day. The quantity of the diurnal motion for any day is found by taking the difference between it and the preceding day.

Thus let the diurnal motion for the 11th of May, 1787, be required.

	SIGNS.	DEC.	MIN.
On the 11th of May her place was	11	2	35
On the 10th of May	-	10	19 47
			<hr/>
The diurnal motion sought		12	48
			<hr/>

T A B L E S

FOR FINDING THE HOURLY MOTION OF THE
MOON, AND THEREBY HER TRUE PLACE
AT ANY TIME OF THE DAY.

T A B L E I.

HOURS.	11 46	11 56	12 6	12 16	12 26	12 36	12 46	12 56	13 6	13 16	13 26
	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.
1	0 29	0 30	0 30	0 30	0 31	0 31	0 32	0 32	0 33	0 33	0 34
2	0 59	1 0	1 0	1 1	1 2	1 3	1 4	1 5	1 5	1 6	1 43
3	1 28	1 20	1 31	1 32	1 33	1 3	1 36	1 37	1 38	1 39	1 41
4	1 58	1 59	2 1	2 3	2 4	2 6	2 8	2 9	2 11	2 13	2 14
5	2 27	2 29	2 31	2 34	2 35	2 3	2 40	2 42	2 4	2 46	2 48
6	2 57	2 59	3 1	3 4	3 6	3 9	3 11	3 14	3 16	3 19	3 21
7	3 26	3 29	3 32	3 35	3 38	3 40	3 43	3 46	3 49	3 52	3 55
8	3 55	3 59	4 2	4 6	4 9	4 12	4 15	4 19	4 22	4 25	4 20
9	4 25	4 28	4 32	4 36	4 40	4 43	4 47	4 51	4 55	4 58	5 2
10	4 54	4 58	5 3	5 7	5 11	5 1	5 19	5 23	5 27	5 32	5 56
11	5 24	5 28	5 33	5 37	5 42	5 4	5 51	5 56	6 0	6 3	6 9
12	5 53	5 58	6 3	6 8	6 13	6 18	6 23	6 28	6 33	6 38	6 43
13	6 22	6 28	6 33	6 39	6 44	6 49	6 55	7 0	7 6	7 11	7 17
14	6 52	6 58	7 3	7 9	7 15	7 21	7 2	7 33	7 3	7 44	7 50
15	7 21	7 27	7 34	7 40	7 46	7 52	7 59	8 5	8 11	8 17	8 24
16	7 51	7 57	8 4	8 11	8 17	8 24	8 31	8 37	8 44	8 51	8 57
17	8 20	8 27	8 34	8 41	8 48	8 55	9 3	9 10	9 1	9 24	9 31
18	8 49	8 57	9 4	9 12	9 19	9 27	9 34	9 42	9 49	9 57	10 4
19	9 19	9 26	9 35	9 43	9 51	9 58	10 6	10 14	10 22	10 30	10 38
20	9 48	9 56	10 5	10 13	10 21	10 30	10 38	10 47	10 55	11 3	11 12
21	10 17	10 26	10 36	10 44	10 53	11 1	11 10	11 19	11 27	11 36	11 43
22	10 47	10 56	11 6	11 15	11 21	11 33	11 42	11 51	12 0	12 10	12 19
23	11 17	11 26	11 36	11 46	11 55	12 4	12 14	12 24	12 33	12 43	12 52
24	11 46	11 56	12 6	12 16	12 26	12 36	12 46	2 56	13 6	13 16	13 26

T A B L E II.

HOURS.	13 30	13 40	13 50	14 00	14 10	14 20	14 30	14 40	14 50	15 00	15 10
	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.
1	0 31	0 34	0 35	0 36	0 36	0 36	0 36	0 37	0 37	0 38	0 38
2	1 8	1 9	1 10	1 10	1 11	1 12	1 13	1 14	1 15	1 15	1 16
3	1 42	1 42	1 46	1 46	1 47	1 48	1 49	1 51	1 51	1 53	1 54
4	2 16	2 8	2 19	2 21	2 22	2 24	2 26	2 28	2 20	2 31	2 33
5	2 50	2 52	2 54	2 56	2 58	3 0	3 3	3 5	3 7	3 9	3 11
6	3 24	3 26	3 29	3 31	3 34	3 39	3 39	3 41	3 45	3 46	3 9
7	3 58	4 1	4 4	4 7	4 10	4 10	4 15	4 18	4 21	4 24	4 7
8	4 32	4 35	4 39	4 42	4 45	4 49	4 52	4 55	4 59	5 2	5 5
9	5 6	5 10	5 13	5 17	4 21	5 25	5 28	5 32	5 36	5 40	5 43
10	5 40	5 42	5 48	5 52	5 57	6 1	6 5	6 9	6 13	6 17	6 22
11	6 14	6 19	6 23	6 28	6 32	6 37	6 41	6 46	6 51	6 55	7 0
12	6 48	6 53	6 58	7 3	7 8	7 13	7 28	7 23	7 28	7 33	7 28
13	7 22	7 27	7 32	7 38	7 44	7 49	7 54	8 6	8 5	8 11	8 10
14	7 56	8 0	8 8	8 13	8 19	8 25	8 31	8 37	8 43	8 48	8 54
15	8 30	8 36	8 42	8 49	8 55	9 1	9 7	9 14	9 20	9 26	9 32
16	9 4	9 11	9 17	9 21	9 12	9 37	9 41	9 51	9 57	10 4	10 11
17	9 38	9 45	9 52	9 59	10 20	10 13	10 20	10 28	10 33	10 42	10 49
18	10 12	10 19	10 27	10 34	10 42	10 49	10 57	11 4	11 12	11 19	11 27
19	10 46	10 54	11 5	11 10	11 18	11 26	11 34	11 41	11 49	11 57	12 5
20	11 20	11 38	11 37	11 24	11 8	12 2	12 10	12 18	12 17	12 35	12 42
21	11 54	12 3	12 11	12 20	12 9	12 38	12 40	12 54	13 4	13 13	13 21
22	12 28	12 37	12 46	12 55	13 5	13 14	13 23	13 35	13 41	13 5	13 50
23	13 2	13 12	13 21	13 31	13 45	13 59	13 59	14 9	14 10	14 28	14 38
24	13 36	13 46	13 56	14 6	14 16	14 26	14 36	14 46	14 56	15 6	15 10

The moon's path may be represented on the globe in a very pleasing manner, by tying a filken line over the surface of the globe, exactly on the ecliptic; then finding, by an ephemeris, the place of the nodes for the given time, confine the silk at these two points, and at 90 degrees distance from them elevate the line about $5\frac{1}{4}$ deg. from the ecliptic, and depress it as much on the other, and it will then represent the lunar orbit for that day.

P R O B L E M LXX.

To find the moon's place in the ecliptic, for any given hour of the day.

First, without an ephemeris, only knowing the age of the moon, which may be obtained from every common almanack.

Elevate the north pole of the celestial globe to 90 degrees. and then the equator will be in the plane of, and coincide with the broad paper circle; bring the first point of Aries, marked γ on the globe, to the day of the new moon on the said broad paper circle, which answers to the sun's place for that day; and the day of the moon's age will stand against the sign and degree of the
moon's

moon's mean place; to which place apply a small patch, to represent the moon.

But if you are provided with an ephemeris,* that will give the moon's latitude and place in the ecliptic; first note her place in the ecliptic upon the globe, and then counting so many degrees amongst the parallels in the zodiac, either above or below the ecliptic, as her latitude is north or south upon the given day, and that will be the point which represents the true place of the moon for that time, to which apply the artificial sun, or a small patch.

Thus on the 11th of May, 1787, she was at noon in 2 deg. 35 min. of Pisces, and her latitude was 4 deg. 18 min.; but as her diurnal motion for that day is 12 48 in nine hours, she will have passed over 4 deg. 47 min. which added to her place at noon, gives 7 h. 22 m. for her place on the 11th of May, at nine at night.

PROBLEM

* The nautical almanack is the best English ephemeris.

P R O B L E M LXXI.

To find the moon's declination for any given day or hour.

The place in her orbit being found, by prob. lxx. bring it to the brazen meridian; then the arch of the meridian contained between it and the equinoctial, will be the declination sought.

P R O B L E M LXXII.

To find the moon's greatest and least meridian altitudes in any given latitude, that of London for example.

It is evident, this can happen only when the ascending node of the moon is in the vernal equinox; for then her greatest meridian altitude will be 5 deg. greater than that of the sun, and therefore about 67 deg.; also her least meridian altitude will be 5 deg. less than that of the sun, and therefore only 10 deg.: there will therefore be 57 deg. difference in the meridian altitude of the moon; whereas that of the sun is but 47 deg.

N. B. When the same ascending node is in the autumnal equinox, then will her meridian altitude differ by only 37 deg.; but this phænomenon can separately happen but once in the revolution of a node, or once in the space of nineteen years: and it will be a pleasant entertainment to place the filken line to cross the ecliptic in the equinoctial points alternately; for then the reason will more evidently appear, why you observe the moon sometimes within 23 deg. of our zenith, and at other times not more than 10 deg. above the horizon, when she is full south.

P R O B L E M LXXIII.

To illustrate, by the globe, the phænomenon of the harvest moon.

About the time of the autumnal equinox, when the moon is at or near the full, she is observed to rise almost at the same time for several nights together; and this phænomenon is called the HARVEST MOON.

This circumstance, with which farmers were better acquainted than astronomers, till within these few years, they gratefully ascribed to the goodness of God, not doubting that he had
ordered

ordered it on purpose to give them an immediate supply of moon-light after sun-set, for their greater conveniency in reaping the fruits of the earth.

In this instance of the harvest moon, as in many others discoverable by astronomy, the wisdom and beneficence of the Deity is conspicuous, who really so ordered the course of the moon, as to bestow more or less light on all parts of the earth, as their several circumstances and seasons render it more or less serviceable.*

About the equator, where there is no variety of seasons, moon-light is necessary for gathering in the produce of the ground; and there the moon rises about 50 minutes later every day or night than on the former.

At considerable distances from the equator, where the weather and seasons are more uncertain, the autumnal full moons rise at sun-set from the first to the third quarter.

At the poles, where the sun is for half a year absent, the winter full moons shine constantly
without

* Ferguson's Astronomy.

without setting, from the first to the third quarter.

But this observation is still further confirmed, when we consider that this appearance is only peculiar with respect to the full moon, from which only the farmer can derive any advantage; for in every other month, as well as the three autumnal ones, the moon, for several days together, will vary the time of it's rising very little; but then in the autumnal months this happens about the time when the moon is at the full; in the vernal months, about the time of new moon; in the winter months, about the time of the first quarter; and in the summer months, about the time of the last quarter.

These phænomena depend upon the different angles made by the horizon, and different parts of the moon's orbit, and that the moon can be full but once or twice in a year, in those parts of her orbit which rise with the least angles.

The moon's motion is so nearly in the ecliptic, that we may consider her at present as moving in it.

The different parts of the ecliptic, on account of it's obliquity to the earth's axis, make very different angles with the horizon as they rise or set. Those parts, or signs, which rise with the smallest angles, set with the greatest, and vice versa. In equal times, whenever this angle is least, a greater portion of the ecliptic rises, than when the angle is larger.

This may be seen, by elevating the globe to any considerable latitude, and then turning it round it's axis in the horizon.

When the moon, therefore, is in those signs which rise or set with the smallest angles, she will rise or set with the least difference of time, and with the greatest difference in those signs which rise or set with the greatest angles.

Thus in the latitude of London, at the time of the vernal equinox, when the sun is setting in the western part of the horizon, the ecliptic then makes an angle of 62 deg. with the horizon; but when the sun is in the autumnal equinox, and setting in the same western part of the horizon, the ecliptic makes an angle but of 15 deg. with the horizon; all which is evident by a bare inspection of the globe only.

Again,

Again, according to the greater or less inclination of the ecliptic to the horizon, so a greater or less degree of motion of the globe about it's axis will be necessary to cause the same arch of the ecliptic to pass through the horizon; and consequently the time of it's passage will be greater or less, in the same proportion; but this will be best illustrated by an example.

Therefore, suppose the sun in the vernal equinox, rectify the globe for the latitude of London, and place of the sun; then bring the vernal equinox, or sun's place, to the western edge of the horizon, and the hour index will point precisely to VI; at which time, we will also suppose the moon to be in the autumnal equinox, and consequently at full, and rising exactly at the time of sun-set.

But on the following day, the sun, being advanced scarcely one degree in the ecliptic, will set again very nearly at the same time as before; but the moon will, at a mean rate, in the space of one day, pass over 13 deg. in her orbit; and therefore, when the sun sets in the evening after the equinox, the moon will be below the horizon, and the globe must be turned about till 13 deg. of Libra come up to the edge of the horizon, and

and then the index will point to 7 h. 16 m. the time of the moon's rising, which is an hour and $\frac{1}{2}$ after sun-set for dark night. The next day following, there will be $2\frac{1}{2}$ hours, and so on successively, with an increase of $1\frac{1}{4}$ h. dark night each evening respectively, at this season of the year; all owing to the very great angle which the ecliptic makes with the horizon at the time of the moon's rising.

On the other hand, suppose the sun in the autumnal equinox, or beginning of Libra, and the moon opposite to it in the vernal equinox, then the globe (rectified as before) being turned about till the sun's place comes to the western edge of the horizon, the index will point to VI, for the time of his setting, and the rising of the full moon on that equinoctial day. On the following day, the sun will set nearly at the same time; but the moon being advanced (in the 24 hours) 13 deg. in the ecliptic, the globe must be turned about till that arch of the ecliptic shall ascend the horizon, which motion of the globe will be very little, as the ecliptic now makes so small an angle with the horizon, as is evident by the index, which now points to VI h. 17 deg. for the time of the moon's rising on the second day, which is but about $\frac{1}{2}$ of an hour after sun-set. The third

G g

day,

day, the moon will rise within $\frac{1}{2}$ an hour ; on the fourth, within $\frac{3}{4}$ of an hour, and so on ; so that it will be near a week before the nights will be an hour without illumination ; and in greater latitudes, this difference will be still greater, as you will easily find by varying the case, in the practice of this celebrated problem, on the globe.

This phænomenon varies in different years ; the moon's orbit being inclined to the ecliptic about 5 degrees, and the line of the nodes continually moving retrograde, the inclination of her orbit to the equator will be greater at some seasons than it is at others, which prevents her hastening to the northward, or descending southward, in each revolution, with an equal pace.

OF THE TIDES.

A tide is that motion of the water in the sea and rivers, by which they are found regularly to rise and fall.

The general cause of the tides was discovered by Sir Isaac Newton, and are deduced from the following considerations.

We find, by constant experience, that all bodies fall down to the earth's surface in perpendicular lines; and as lines perpendicular to the surface of a sphere, tend towards the center, therefore the lines, along which all heavy bodies fall, are directed towards the earth's center.

As these bodies apparently fall by their weight or gravity, the law by which they fall is called the law of gravitation.

Now as bodies, by their gravity, fall towards the earth, it has not been deemed improper to say, that the earth attracts those bodies, and therefore, in respect to the earth, the word GRAVITATION and ATTRACTION may be used one for the other, as by them is meant no more than the

power, or law, by which bodies tend towards it's center.

Sir Ifaac Newton, by a sagacity peculiar to himself, discovered from many observations, that this law of gravitation or attraction was universally diffused throughout the solar system, and that the regular motions observed among the heavenly bodies, were governed by the same principle; so that the earth and moon attracted each other, and were both of them attracted by the sun. Also, that the force of attraction, exerted by these bodies one on the other, was less as the distance increased, in proportion to the squares of those distances.

It is not in the motion of the celestial bodies only, that the effects of this mutual gravitation is visible; we are now to explain by the same principle, a phænomenon which passes upon the earth, the ebbing and flowing of the sea.

As the earth is attracted by the sun and moon, the parts of the earth will not gravitate towards it's center in the same manner as if those parts were not affected by such attractions.

It is also very evident, that if the earth was entirely free from these actions of the sun and moon, the oceans would then be equally attracted towards it's center, on all sides, by the force of gravity, and would continue in perfect stagnation, without ever ebbing or flowing.

But as the ocean is not free from these actions, it must needs rise higher in those places where the sun and moon diminish it's gravity, or where the sun and moon have the greatest attraction.

As the force of gravity will be most diminished in those parts of the earth where her attraction is most powerful, (which must be when she is nearest to, or in the zenith of those places) the waters in those parts will rise highest, and it will be *FULL SEA*, or *FLOOD*, in such places.

The parts of the earth directly under the moon, and those also in their nadir, or such places as are diametrically opposite to those where the moon is in the zenith, will have the flood, or high water, at the same time.

For either hemisphere of the earth would gravitate equally towards the other half, were they free from all external attraction.

But by the action of the moon, the gravitation of one hemisphere towards the center is diminished, and that of the other is increased.

Now in the hemisphere next the moon, the parts in the zenith being most attracted, and thereby their gravitation towards the earth's center diminished; consequently, the waters in those parts must be higher than in any other part of this hemisphere.

But in the hemisphere which is most remote from the moon, the nadir, or most distant point, being less attracted by the moon than those parts that are nearer, is left as it were behind, while all the other parts, and even the center itself, is more attracted towards her, and consequently the water will be higher in that point than at any other part of this hemisphere.

The two middle points will therefore be highest in their respective hemispheres; the one being really more ELEVATED, the other less DEPRESSED by the moon's attraction, than the adjacent parts.

Those parts of the earth where the moon appears in the horizon, or is 90 degrees distant from the zenith and nadir, will have the ebbs or lowest waters.

For as the waters in the zenith and nadir rise at the same time, the waters in their neighbourhood will press towards those places, to maintain the equilibrium; and to supply the place of these, others will move the same way, and so on to places at 90 degrees distant from the zenith and nadir; consequently, in those places where the moon appears in the horizon, the waters will have more liberty to descend towards the center, and therefore in those places they will be the lowest.

Hence it plainly follows, that if the surface of the earth was covered with water, it would put on a spheroidal, or egg-like figure, whose longest diameter would pass through the place where the moon is vertical, and the shortest diameter will be where she is in the horizon; and as the moon apparently shifted her position from east to west, in going round the earth every day, the longer diameter of the spheroid would follow her motion, and thus occasion the two floods and ebbs

observable in about every 25 hours, which is about the length of a lunar day.

Hence in any place, the greater the moon's mid-day altitude, the greater the evening tides will be; and the greater the midnight depression, the greater the tides will be.

The summer evening and the winter morning tides are highest, because the moon's summer altitude, and winter depression, are greatest, especially when her declination is north in summer, and south in winter.

The time of high water is not precisely at the time of the moon's coming to the meridian, but about an hour or two after.

For the moon acts with some force after she has past the meridian, and thereby adds to the libration, or waving motion, which she has put the water into, whilst she was in the meridian, in the same manner as a small force applied upwards to a ball already raised to some height, will raise it still higher.

The tides are greater than ordinary twice every month, that is, about the times of new and full moon; they are called SPRING TIDES.

For at these times the actions of both sun and moon concur to draw in the same right line; and therefore the sea must be most elevated. In conjunction, or when the sun and moon are on the same side of the earth, they both conspire to raise the water in the zenith, and consequently in the nadir. And when the sun and moon are in opposition, that is, when the earth is between them, whilst one makes high water in the zenith and nadir, the other does the same in the nadir and zenith.

The tides are less than ordinary twice every month, that is, about the times of the first and last quarters of the moon; and these are called NEAP TIDES.

Because in these quarters of the moon, the sun raises the waters where the moon depresses it; and depresses where the moon raises; so that the tides are made only by the difference of their actions.

It is to be observed, that the spring tides do not happen directly on the new and full moons, but rather a day or two after, when the action of the sun and moon have conspired together for a considerable time. In like manner, the neap tides happen a day or two after the quarters.

When the moon is in her perigæum, or nearest approach to the earth, the tides increase more in the same circumstances than at other times.

The spring tides are greatest about the times of the equinoxes, that is, about the latter end of March and September, than at any other times of the year, and the neap tides are the less.

Because the longer diameter of the spheroid will at that time be in the earth's equator, and consequently describe a great circle of the earth, by whose diurnal rotation the floods will move swifter, as describing a great circle in the same time they used to describe a lesser circle, by which means the waters will be thrown more forcibly against the shores, and must rise higher.

The circumstances hitherto explained, would always take place, if the whole surface of the
earth

earth was covered with sea ; but since it is not so, there arise a great many different appearances, which require particular solutions, in which the situation of the shores, &c. must be considered ; for these, we must refer the reader to larger works on astronomy.

Small inland seas, such as the Mediterranean and the Baltic, are but little subject to tides ; because the action of the sun and moon is nearly equal at both extremities. In very high latitudes the tides are also very inconsiderable ; for the sun and moon always acting near the equator, and raising the water towards the torrid zone, the neighbourhood of the poles must be consequently deprived of those waters, and the sea must be low, relative to other parts.

P R O B L E M LXXIV.

To find what azimuth the moon is upon at any place when it is flood, or high water ; and thence the high tide for any day of the moon's age at the same place.

Having observed the hour and minute of high water, about the time of new or full moon, rectify the globe to the latitude and sun's place ; find the
moon's

moon's place and latitude in an ephemeris, to which set the artificial moon,* and screw the quadrant of altitude in the zenith ; turn the globe till the horary index points to the time of flood, and lay the quadrant over the center of the artificial moon, and it will cut the horizon in the point of the compass upon which the moon was, and the degrees on the horizon contained between the strong brass meridian and the quadrant, will be the moon's azimuth from the south.

To find the time of high water at the same place.

Rectify the globe to the latitude and zenith, find the moon's place by an ephemeris for the given day of her age, or day of the month, and set the artificial moon to that place in the zodiac ; put the quadrant of altitude to the azimuth before found, and turn the globe till the artificial moon is under it's graduated edge, and the horary index will point to the time of the day on which it will be high water.

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* Or patch representing the moon.

THE USE OF THE CELESTIAL GLOBE IN THE
SOLUTION OF PROBLEMS ASCERTAINING THE
PLACES AND VISIBLE MOTIONS OR ORBITS
OF COMETS.*

There is another class, or species of planets, which are called COMETS. These move round the sun in regular and stated periods of times, in the same manner, and from the same cause, as the rest of the planets do ; that is, by a centripetal force, every where decreasing as the squares of the distances increase, which is the general law of the whole planetary system. But this centripetal force in the comets being compounded with the projectile force, in a very different ratio from that which is found in the planets, causes their orbits to be much more eclipical than those of the planets, which are almost circular.

But whatever may be the form of a comet's orbit in reality, their geocentric motions, or the apparent paths which they describe in the heavens among the fixed stars, will always be circular, and therefore may be shewn upon the surface of a celestial globe, as well as the motions and places of any of the rest of the planets.

To

* Martin's Description and Use of the Globes.

To give an instance of the cometary praxis on the globe, we shall chuse that comet, for the subject of these problems, which made it's appearance at Boston, in New England, in the months of October and November, 1758, in it's return to the sun; after which, it approached so near the sun, as to set HELIACALLY, or to be lost in it's beams for some time, spent in passing the perihelion. Then afterwards emerging from the solar rays, it appeared retrograde in it's course from the sun towards the latter end of March, and so continued the whole month of April, and part of May, in the West Indies, particularly in Jamaica, whose latitude rendered it visible in those parts, when it was, for the greatest part of the time, invisible to us, by reason of it's southern course through the heavens.

When two observations can be made of a comet, it will be very easy to assign it's course, or mark it out upon the surface of the celestial-globe. These, with regard to the above-mentioned comet, we have, and they are sufficient for our purpose in regard to the solution of cometary problems.

By an observation made at Jamaica on the 31st of March, 1759, at 5 o'clock in the morning,
the

the comet's altitude was found to be 22 deg. 50 min. and it's azimuth 71 deg. south-east. From hence we shall find it's place on the surface of the globe, by the following problem.

P R O B L E M LXXV.

To rectify the globe for the latitude of the place of observation in Jamaica, latitude 17 deg. 30 min. and given day of the month, viz. March 31st.

Elevate the north pole to 17 deg. 30 min. above the horizon, then fix the quadrant of altitude to the same degree in the meridian, or zenith-point. Again, the sun's place for the 31st of March is in 10 deg. 34 min. γ , which bring to the meridian, and set the hour index at XII, and the globe is then rectified for the place and time of observation.

P R O B L E M LXXVI.

To determine the place of a comet on the surface of the celestial globe from it's given altitude, azimuth, hour of the day, and latitude of the place.

The

The globe being rectified to the given latitude, and day of the month, turn it about towards the east, till the hour index points to the given time, viz. V o'clock in the morning; then bring the quadrant of altitude to intersect the horizon in 71 deg. the given azimuth in the south-east quarter; then, under 22 deg. 50 min. the given altitude, you will find the comet's place, where you may put a small patch to represent it.

P R O B L E M LXXVII.

To find the latitude, longitude, declination, and right ascension of the comets.

In the circles of latitude contained in the zodiac, you will find the latitude of the comet to be about 3 deg. 30 min. from the ecliptic; the same circle of latitude reduces it's place to the ecliptic in 26 deg. 30 min. of ϖ , which is it's longitude sought. Then bring the cometary patch to the brazen meridian, and it's declination will be shewn to be 9 deg. 15 min. south. At the same time, it's right ascension will be 327 deg. 30 min.

P R O B L E M LXXVIII.

To shew the time of the comet's rising, southing, setting, and amplitude, for the day of the observation at Jamaica.

Bring the place of the comet into the eastern semi-circle of the horizon, (the globe being rectified as directed) the index will point to III hours 15 min. which is the time of it's rising in the morning at Jamaica, the amplitude 10 deg. very nearly, to the south. The patch being brought to the meridian, the index points to IX o'clock 10 min. for the time of culminating, or being south to them. Lastly, bring the patch to touch the western meridian, and the index will point to III in the afternoon, for the time of the comet's setting, with 10 deg. of southern amplitude, of course.

P R O B L E M LXXIX.

From the comet's place being given, to find the time of it's rising in the horizon of London, on the 31st day of March, 1759.

For this purpose, you need only rectify the globe for the given latitude of London, and bring the cometary patch to the eastern horizon, and the index points to III hours, 45 min. for the time of it's rising at London, with about 14 deg. of south amplitude; then turn the patch to the western horizon, and the index points to II h. 25 min. the time of it's setting.

N. B. From hence it appears, the comet rose soon enough that morning to have been observed at London, had the heavens been clear, and the astronomers been before-hand apprized of such a phænomenon.

P R O B L E M LXXX.

To determine another place of the same comet, from an observation made at London on the 6th day of May, at X in the evening.

On the 6th day of May, 1759, at X at night, the place of the comet was observed, and it's distance measured with a micrometer, from two fixed stars marked μ and ν in the constellation called HYDRA, and it's altitude was found to be 16 deg. and it's azimuth 37 deg. south-west, from whence it's place on the surface

surface of the globe is exactly determined, as in prob. lxxvi. and having stuck a patch thereon, you will have the two places of the comet on the surface of the globe, for the two distant days and places of observation, as required.

P R O B L E M LXXXI.

From two given places of a comet, to assign it's apparent path among the fixed stars in the heavens.

The two places of the comet being determined by the observations on the 31st of March, 1758, and the 6th of May following, and denoted by two patches respectively, you must move the globe up and down, in the notches of the horizon, till such time you bring both the patches to coincide with the horizon; then will the arch of the horizon between the two patches shew, upon the celestial globe, the apparent place of the comet in the interval between the two observations, and by drawing a line with a black lead pencil along by the frame of the horizon, it's path on the surface of the globe will be delineated, as required. And here it may be observed, that it's apparent path lay through the following southern constellations, viz. the tail of Capricorn,

the tail of *Pisces Australis*, by the head of *Indus*, the neck and body of *Pavo*, through the neck of *Apus*, below *Triangulum Australe*, above *Musca*, by the lowermost of the *Crociæ*, across the hind legs and through the tail of *Centaurus*, from thence between the two stars in the back of the *Hydra* before-mentioned; after this, it passed on to *Sextans Urania*, and then to the ecliptic near *Cor Leonis*; soon after which, it totally disappeared.

PROBLEM LXXXII.

To estimate the apparent velocity of a comet, two places thereof being given by observation.

Let one place be ascertained near the beginning of it's appearance, and the other towards the end thereof; then bring these two places to the horizon, and count the number of degrees intersected between them, which being the space apparently described in a given time, will be the velocity required. Thus, in the case of the above-mentioned comet, you will find, that it described more than 150 deg. in the space of 36 days, which is more than 4 deg. per day.

P R O B L E M LXXXIII.

To represent the general phænomena of the comet, for any given latitude.

Bring the visible path of the comet to coincide with the horizon, by which it was drawn, and then observe what degree of the meridian is in the north point of the horizon, which, in the case of the foregoing comet, will be the 23 deg. This will shew the greatest latitude in which the whole path can be visible in any latitude less than this, as that of Jamaica; where, for instance, the most southern part of the path will be elevated more than 5 deg. above the horizon, and the comet visible through the whole time of it's apparition. But rectifying the globe for the latitude of London, the path of the said comet will be for the most part invisible, or below the horizon; and therefore it could not have been seen in our latitude, but at times very near the beginning and end of it's appearance; because, by bringing the comet's path on one part to the south point of the horizon, it will immediately appear in what part the comet ceases to be visible; and then bringing the other part of the path to

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the

the point, it will appear in what part it will again become visible.

After this manner may the problems relating to any other comets be performed; and thus the paths of the several comets, which have hitherto been observed, may be severally delineated on the celestial globe, and their various phænomena in different latitudes be thereby shewn.

THE USE OF THE CELESTIAL GLOBE, IN PROBLEMS RELATIVE TO THE FIXED STARS.

The use of the celestial globe is in no instance more conspicuous, than in the problems concerning the fixed stars. Among many other advantages, it will, if joined with observations on the stars themselves, render the practice and theory of other problems easy and clear to the pupil, and vastly facilitate his progress in astronomical knowledge.

The heavens are as much studded over with stars in the day, as in the night; only that they are then rendered invisible to us, by the brightness of the solar rays. But when this glorious luminary descends below the horizon, they begin gradually

gradually to appear. When the sun is about 12 degrees below the horizon, stars of the first magnitude become visible: when he is 13 degrees, those of the second are seen: when 14 degrees, stars of the third magnitude appear: when 15 degrees, those of the fourth present themselves to view: when he is descended about 18 degrees, the stars of the fifth and sixth magnitude, and those that are still smaller, become conspicuous, and the azure arch sparkles with all it's glory.

P R O B L E M LXXXIV.

To find the right ascension and declination of any given star.

Bring the given star to the meridian, and the degree under which it lies is it's declination; and the point in which the meridian intersects the equinoctial is it's right ascension. For instance, let Arcturus be the given star; this brought to the meridian will be seen under the 20 deg. 20 min. which is therefore it's declination, north; and it's right ascension is, at the same time, shewn in the equinoctial to be 211 deg. Again, another instance may be Sirius, the dog-star,

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which,

which, brought to the meridian, will be seen under the 16 deg. 30 min. which is his declination, south; and it's right ascension 98 deg. 20 min. in the equinoctial line.

P R O B L E M LXXXV.

To find the latitude and longitude of a given star.

Bring the pole of the ecliptic to the meridian, over which fix the quadrant of altitude, and holding the globe very steady, move the quadrant to lie over the given star, and it will cut that degree in the edge, as will shew it's latitude from the ecliptic, and in the ecliptic the quadrant will cut that degree which is called it's place REDUCED TO THE ECLIPTIC, or longitude, from the beginning of Aries. Thus, with respect to Arcturus, it's latitude from the ecliptic will be found 30 deg. 30 min. and it's longitude in the ecliptic about 20 deg. 20 min. of Libra. This problem regards either pole, as the stars are in the northern or southern hemispheres, respectively.

PROBLEM LXXXVI.

The right ascension and declination of a star being given, to find it's place on the globe.

Turn the globe till the meridian cuts the equinoctial in the degree of right ascension. Thus, for example, suppose the right ascension of Aldebaran to be 65 deg. 30 m. and it's declination to be 16 deg. north, then turn the globe about till the meridian cuts the equinoctial in 65 deg. 30 min. and under the 16 deg. of the meridian, on the northern part, you will observe the star Aldebaran, or the bull's eye.

PROBLEM LXXXVII.

To find the time of the rising, southing, setting, amplitude, &c. of any star, in a given latitude and day of the year.

The precept is the same as in the problems for the sun. Thus, let it be required to know at what time the Pleiades (or seven stars) rise, set, &c. in the latitude of London, on the 11th of May. The globe being rectified for the latitude of London, and the sun's place for the given day,
turn

turn the globe about till you bring the Pleiades into the eastern semi-circle of the horizon, and the index will point to 34 deg. 45 min. the time of their rising in the morning. Then bring the said cluster of stars to the meridian, and the index will point to about $\frac{1}{2}$ after XII for the time of their culminating, or being upon the meridian. Lastly, bring them into the western horizon, and the index will point to VIII 40 min. which shews the time of their setting in the evening of that day. It will also appear, on the circle of the horizon, that they rise with about 40 deg. of amplitude to the north, and set with the same amplitude from the west.

P R O B L E M LXXXVIII.

To find what constellation any remarkable star, seen in the firmament, belongs to.

Bring the sun's place in the ecliptic for that day to the strong brass meridian, and set the horary index to that XII which is most elevated; the celestial globe being rectified to the latitude, turn the globe till it points to the present hour; and by the help of the mariner's compass, and attending to the variation, which at London is

nearly 24 degrees from the north, westward, set the north pole of the globe towards the north pole of the heavens.

The star upon the globe (if you conceive yourself in the center) which directs towards that point in the heavens, in which the star you want to know is seen, is the star required.

At the same time, by comparing the stars in the heavens with those upon the globe, the other stars and their constellations may be easily known; whereby you will be enabled, any star-light night, to point out many of those stars called correspondents to various places on the earth.

P R O B L E M LXXXIX.

To find at what hour any known star passes the meridian on any day in the year.

Rectify the globe to the latitude, and set the artificial sun to his place in the ecliptic; bring it's center under the strong brass meridian, and set the horary index to XII; then turn the globe till the star comes to the meridian, and the horary index will point upon the equator to the hour
on

on which that star will be upon the fourth part of the meridian.

If you turn the globe on till the center of the artificial sun is under that graduated side of the brass meridian, which is below the elevated pole, all those stars, which are then cut by that side of the meridian above the said pole, will pass the meridian at midnight.

P R O B L E M X C.

To find on what day of the year any star passes the meridian at any proposed hour of the night.

Bring the star to the strong brass meridian, and set the horary index to the proposed hour; then turn the globe till the index points to XII, and that degree on the ecliptic, which is cut by the meridian, is the sun's place, against which, in the calendar upon the broad paper circle, is the day of the month.

PROBLEM XCI.

To trace the circles of the sphere in the starry firmament.

We shall solve this problem for the time of the autumnal equinox; because that intersection of the equator and ecliptic will be directly under the depressed part of the meridian about midnight; and then the opposite intersection will be elevated above the horizon; and also because our first meridian upon the terrestrial globe passing through London, and the first point of Aries, when both globes are rectified to the latitude of London, and to the sun's place, and the first point of Aries is brought under the graduated side of each of their meridians, we shall have the corresponding face of the heavens and the earth represented, as they are with respect to each other at that time, and the principal circles of each sphere will correspond with each other.

The horizon is then distinguished, if we begin from the north and count westward, by the following constellations; the hounds and waist of Bootes, the northern crown, the head of Hercules, the shoulders of Serpentarius, and Sobieski's

eski's shield; it passes a little below the feet of Antinous, and through those of Capricorn, through the Sculptor's frame, Eridanus, the star Rigell in Orion's foot, the head of Monoceros, the crab, the head of the little lion, and lower part of the great bear.

The meridian is then represented by the equinoctial colure, which passes through the star marked δ in the tail of the little bear, under the north pole, the pole star, one of the stars in the back of Cassiopea's chair marked β , the head of Andromeda, the bright star in the wing of Pegasus marked γ , and the extremity of the tail of the whale.

That part of the equator which is then above the horizon, is distinguished on the western side by the northern part of Sobieski's shield, the shoulder of Antinous, the head and vessel of Aquarius, the belly of the western fish in Pisces; it passes through the head of the whale, and a bright star marked δ in the corner of his mouth, and thence through the star marked δ in the belt of Orion, at that time near the eastern side of the horizon.

That

That half of the ecliptic which is then above the horizon, if we begin from the western side, presents to our view Capricornus, Aquarius, Pisces, Aries, Taurus, Gemini, and a part of the constellation Cancer.

The solstitial colure, from the western side, passes through Cerberus, and the hand of Hercules, thence by the western side of the constellation Lyra, and through the dragon's head and body, through the pole point under the polar star, to the east of Auriga, through the star marked γ in the foot of Castor, and through the hand and elbow of Orion.

The northern polar circle, from that part of the meridian under the elevated pole, advancing towards the west, passes through the shoulder of the great bear, thence a little to the north of the star marked α in the dragon's tail, the great knot of the dragon, the middle of the body of Cepheus, the northern part of Cassiopea, and base of her throne, through Camelopardalus, and the head of the great bear.

The tropic of Cancer, from the western edge of the horizon, passes under the arm of Hercules, under the vulture, through the goose and fox,

fox, which is under the beak and wing of the swan, under the star called Sheat, marked β in Pegasus, under the head of Andromeda, and through the star marked ϕ in the fish of the constellation Pisces, above the bright star in the head of the ram marked α , through the Pleiades, between the horns of the bull, and through a group of stars at the foot of Castor, thence above a star marked δ , between Castor and Pollux, and so through a part of the constellation Cancer, where it disappears by passing under the eastern part of the horizon.

The tropic of Capricorn, from the western side of the horizon, passes through the belly, and under the tail of Capricorn, thence under Aquarius, through a star in Eridanus marked c , thence under the belly of the whale, through the base of the chemical furnace, whence it goes under the hare at the feet of Orion, being there depressed under the horizon.

The southern polar circle is invisible to the inhabitants of London, by being under our horizon.

Arctic and antarctic circles, or circles of perpetual apparition and occultation.

The largest parallel of latitude on the terrestrial globe, as well as the largest circle of declination on the celestial, that appears entire above the horizon of any place in north latitude, was called by the ancients the arctic circle, or circle of perpetual apparition.

Between the arctic circle and the north pole in the celestial sphere, are contained all those stars which never set at that place, and seem to us, by the rotative motion of the earth, to be perpetually carried round above our horizon, in circles parallel to the equator.

The largest parallel of latitude on the terrestrial, and the largest parallel of declination on the celestial globe, which is entirely hid below the horizon of any place, was by the ancients called the antarctic circle, or circle of perpetual occultation.

This circle includes all the stars which never rise in that place to an inhabitant of the northern hemisphere, but are perpetually below the horizon.

All arctic circles touch their horizons in the north point, and all antarctic circles touch their horizons in the south point ; which point, in the terrestrial and celestial spheres, is the intersection of the meridian and horizon.

If the elevation of the pole be 45 degrees, the most elevated part either of the arctic or antarctic circle, will be in the zenith of the place.

If the pole's elevation be less than 45 degrees, the zenith point of those places will fall without it's arctic or antarctic circle ; if greater, it will fall within.

Therefore, the nearer any place is to the equator, the lesser will it's arctic and antarctic circles be ; and on the contrary, the farther any place is from the equator, the greater they are. So that,

At the poles, the equator may be considered as both an arctic and antarctic circle, because it's plane is coincident with that of the horizon.

But at the equator (that is, in a right sphere) there is neither arctic nor antarctic circle.

They

They who live under the northern polar circle, have the tropic of Cancer for their arctic, and that of Capricorn for their antarctic circle.

And they who live on either tropic, have one of the polar circles for their arctic, and the other for their antarctic circle.

Hence, whether these circles fall within or without the tropics, their distance from the zenith of any place is ever equal to the difference between the pole's elevation, and that of the equator above the horizon of that place.

From what has been said, it is plain there may be as many arctic and antarctic circles, as there are individual points upon any one meridian, between the north and south poles of the earth.

Many authors have mistaken these mutable circles, and have given their names to the immutable polar circles, which last are arctic and antarctic circles, in one particular case only, as has been shewn.

P R O B L E M X C I I .

To find the circle, or parallel of perpetual apparition, or occultation of a fixed star in a given latitude.

By rectifying the globe to the latitude of the place, and turning it round on it's axis, it will be immediately evident, that the circle of perpetual apparition is that parallel of declination which is equal to the complement of the given latitude northward ; and for the perpetual occultation, it is the same parallel southward, that is to say, in other words, all those stars, whose declinations exceed the co-latitude, will always be visible, or above the horizon ; and all those in the opposite hemisphere, whose declination exceeds the co-latitude, never rise above the horizon.

For instance ; in the latitude of London 51 deg. 30 min. whose co-latitude is 38 deg. 30 min. gives the parallels desired ; for all those stars which are within the circle, towards the north pole, never descend below our horizon ; and all those stars which are within the same circle, about the south pole, can never be seen in the latitude of London, as they never ascend above it's horizon.

P R O B L E M

P R O B L E M X C I I I .

To represent the face of the heavens on the globe for a given hour on any day of the year.

Rectify the globe to the given latitude of the place and day of the month, setting it due north and south by the needle; then turn the globe on it's axis till the index points to the given hour of the night; then all the upper hemisphere of the globe will represent the visible face of the heavens for that time, by which it will be easily seen what constellations and stars of note are then above our horizon, and what position they have with respect to the points of the compass. In this case, supposing the eye was placed in the center of the globe, and holes were pierced through the centers of the stars on it's surface, the eye would perceive through those holes the various corresponding stars in the firmament; and hence it would be easy to know the various constellations at sight, and to be able to call all the stars by their names.

The use of this problem is most extensive, as it acquaints us at any time with the apparent face or state of the heavens, and shews us when the moon, or any of the planets, may be seen, or

fit for examination by the telescope. We can also from hence learn, when any of those curious and wonderful objects, called NEBULOUS STARS, may be seen, and which strike the mind of the observer with amazement, by presenting to his view an indefinite number of the smallest fixed stars through the whole field of view in his telescope.

From hence also, the position of that very extraordinary phænomenon called the GALAXY, or MILKY WAY, is at any time known.

This single problem, therefore, may be considered in itself as sufficient to recommend the use of the celestial globe, to every studious and rational mind, as the most necessary instrument of his celestial tuition.

P R O B L E M XCIV.

The latitude of the place, the sun's place, and the hour of the night being given, to find the azimuth and altitude of any known fixed star.

Rectify the globe for the latitude of the place, and the sun's place; turn the globe till the hour index points to the given hour; then fix the quadrant

drant of altitude in the zenith, and lay it over the star, and it will shew the altitude and azimuth of it.

It was by observing the times of the risings and settings of the fixed stars, or the times of their culminating or passing the meridian, that the ancients determined the hour or time of night.

P R O B L E M X C V .

The latitude of the place, the sun's place, and the azimuth of any known star being given, to find the hour of the night.

Having rectified the globe for the latitude of the place and the sun's place, if the given star be due north or south, bring it to the meridian, and the index will shew the hour of the night.

If the star be in any other direction, fix the quadrant of altitude in the zenith, and set it to the star's azimuth in the horizon; turn the globe about until the quadrant cuts the center of the star, and then the horary index will shew the hour of the night.

But as it may possibly happen that we may see a star, and would be glad to know what star it is, or whether it may not be a new star, or a comet; how that may be discovered, will be seen under the following

P R O B L E M XCVI.

The latitude of the place, the sun's place, the hour of the night, and the altitude and azimuth of any star being given, to find the star.

Rectify the globe for the latitude of the place, and the sun's place; fix the quadrant of altitude in the zenith, and turn the globe till the hour index points to the given hour, and set the quadrant of altitude to the given azimuth; then the star that cuts the quadrant in the given altitude, will be the star sought.

Though two stars, that have different right ascensions, will not come to the meridian at the same time, yet it is possible that in a certain latitude they may come to the same vertical circle at the same time; and that consideration gives the following

P R O B L E M XCVII.

The latitude of the place, the sun's place, and two stars, that have the same azimuth, being given, to find the hour of the night.

Rectify the globe for the latitude, the zenith, and the sun's place; then turn the globe, and also the quadrant about, till both the stars coincide with it's edge; the hour index will shew the hour of the night, and the place where the quadrant cuts the horizon, will be the common azimuth of both stars.

What hath been observed above, of two stars that have the same azimuth, will hold good likewise of two stars that have the same altitude; from whence we have the following

P R O B L E M XCVIII.

The latitude of the place, the sun's place, and two stars, that have the same altitude, being given, to find the hour of the night.

Rectify the globe for the latitude of the place, the zenith, and the sun's place; turn the globe, so that the same degree on the quadrant shall cut
both

both stars, then the hour index will shew the hour of the night.

In the former propositions the latitude of the place is supposed to be given, or known. But as it is frequently necessary to find the latitude of the place, and especially at sea, how this may be found, in a rude manner at least, having the time given by a good clock, or watch, will be seen in the following

P R O B L E M XCIX.

The sun's place, the hour of the night, and two stars, that have the same azimuth, or altitude, being given, to find the latitude of the place.

Rectify the globe for the sun's place, and turn it, till the index points to the given hour of the night; keep the globe from turning, and move it up and down in the notches, till the two given stars have the same azimuth, or altitude; then the brass meridian will shew the height of the pole, and consequently the latitude of the place.

P R O B L E M C.

Two stars being given, one on the meridian, and the other on the east and west part of the horizon, to find the latitude of the place.

Bring the star observed on the meridian to the meridian of the globe; then keeping the globe from turning round it's axis, slide the meridian up or down in the notches, till the other star is brought to the east or west part of the horizon; and that elevation of the pole will be the latitude of the place sought.

O B S E R V A T I O N.

From what hath been said, it appears, that if, of these five things, 1. the latitude of the place; 2. the sun's place in the ecliptic; 3. the hour of the night; 4. the common azimuth of two known fixed stars; 5. the equal altitude of two known fixed stars; any THREE of them be given, the remaining two will easily be found.

There are three sorts of risings and settings of the fixed stars, taken notice of by ancient authors, and commonly called POETICAL RISINGS and
SETTINGS,

SETTINGS, because mostly taken notice of by the poets.

These are the COSMICAL, ACHRONICAL, and HELIACAL.*

They are to be found in most authors that treat on the doctrine of the sphere, and are now chiefly useful in comparing and understanding passages in the ancient writers; such are Hesiod, Virgil, Columella, Ovid, Pliny, &c. How they are to be found by calculation, may be seen in Petavius's Uranologion, and Dr. Gregory's astronomy.

DEFINITION.

When a star rises or sets at sun-rising, it is said to rise or set COSMICALLY.

From whence we shall have the following

PROBLEM CI.

The latitude of the place being given, to find, by the globe, the time of the year when a given star rises or sets cosmically.

Let

* Costard's History of Astronomy.

Let the given place be Rome, whose latitude is 42 deg. 8 min. north; and let the given star be the Lucida Pleiadum. Rectify the globe for the latitude of the place; bring the star to the edge of the eastern horizon, and mark the point of the ecliptic rising along with it; that will be found to be Taurus, 18 deg. opposite to which, on the horizon, will be found May the 8th. The Lucida Pleiadum, therefore, rises cosmically May the 8th.

If the globe continues rectified as before, and the Lucida Pleiadum be brought to the edge of the western horizon, the point of the ecliptic, which is the sun's place, then rising on the eastern side of the horizon, will be Scorpio, 29 deg. opposite to which, on the horizon, will be found November the 21st. The Lucida Pleiadum, therefore, sets cosmically November the 21st.

In the same manner, in the latitude of London, Sirius will be found to rise cosmically August the 10th, and to set cosmically November the 10th.

It is of the cosmical setting of the Pleiades, that Virgil is to be understood in this line,

ANTE TIBI EOÆ ATLANTIDES ABSCONDANTUR,*

and not of their SETTING IN THE EAST, as some have imagined, where stars rise, but never set.

DEFINITION.

When a star rises or sets at sun-setting, it is said to rise or set ACHRONICALLY.

Hence, likewise, we have the following

PROBLEM CII.

The latitude of the place being given, to find the time of the year when a given star will rise or set achronically.

Let the given place be Athens, whose latitude is 37 deg. north, and let the given star be Arcturus.

Rectify the globe for the latitude of the place, and bringing Arcturus to the eastern side of the horizon, mark the point of the ecliptic then setting on the western side; that will be found Aries,

12

* Georg. l. 1, v. 221.

12 deg. opposite to which, on the horizon, will be found April the 2d. Therefore, Arcturus rises at Athens achronically April the 2d.

It is of this rising of Arcturus that Hesiod speaks in his Opera & Dies.*

When from the SOLSTICE sixty days are past,
At eve ARCTURUS rises in the east.

If the globe continues rectified to the latitude of the place, as before, and Arcturus be brought to the western side of the horizon, the point of the ecliptic setting along with it will be Sagittary, 7 deg. opposite to which, on the horizon, will be found November the 29th. At Athens, therefore, Arcturus sets achronically November the 29th.

In the same manner Aldebaran, or the bull's eye, will be found to rise achronically May the 22d, and to set achronically December the 19th.

DEFINITION.

* Lib. ii. ver. 185.

DEFINITION.

When a star first becomes visible in the morning, after it hath been so near the sun as to be hid by the splendor of his rays, it is said to rise HELIACALLY.

But for this there is required some certain depression of the sun below the horizon, more or less, according to the magnitude of the star. A star of the first magnitude is commonly supposed to require that the sun be depressed 12 deg. perpendicularly below the horizon.

This being premised, we have the following

PROBLEM CIII.

The latitude of the place being given, to find the time of the year when a given star will rise heliacally.

Let the given place be Rome, whose latitude is 42 deg. north, and let the given star be the bright star in the bull's horn.

Rectify the globe for the latitude of the place, screw on the brass quadrant of altitude in it's zenith, and turn it to the western side of the horizon. Bring the star to the eastern side of the horizon, and mark what degree of the ecliptic is cut by 12 deg. marked on the quadrant of altitude; that will be found to be Capricorn, 3 deg. the point opposite to which is Cancer, 3 deg. and opposite to this will be found, on the horizon, June the 25th. The bright star, therefore, in the bull's horn, in the latitude of Rome, rises heliacally June the 25th.

These kinds of risings and settings are not only mentioned by the poets, but likewise by the ancient physicians and historians.

Thus Hippocrates, in his book *De Ære*, says, "one ought to observe the heliacal risings and settings of the stars, especially the DOG STAR, and ARCTURUS; likewise the COSMICAL setting of the PLEIADES."

And Polybius, speaking of the loss of the Roman fleet, in the first Punic war, says, "it was not so much owing to fortune, as to the obstinacy of the consuls, in not hearkening to their pilots, who dissuaded them from putting to sea

at that season of the year, which was between the rising of ORION and the DOG STAR; it being always dangerous, and subject to storms." *

DEFINITION.

When a star is first immersed in the evening, or hid by the sun's rays, it is said to set heliacally.

And this again is said to be, when a star of the first magnitude comes within 12 degrees of the sun, reckoned in the perpendicular.

Hence again we have the following

PROBLEM CIV.

The latitude of the place being given, to find the time of the year when a given star sets heliacally.

Let the given place be Rome, in latitude 42 deg. north, and let the given star be the bright star in the bull's horn. Rectify the globe for the latitude of the place, and bring the star to the edge of the western horizon; turn the quadrant of altitude, till 12 deg. cut the ecliptic on the

* Lib. i. p. 53.

the eastern side of the meridian. This will be found to be 7 deg. of Sagittary, the point opposite to which, in the ecliptic, is 7 deg. of Gemini; and opposite to that, on the horizon, is May the 28th, the time of the year when that sets heliacally in the latitude of Rome.

OF THE PRECESSION OF THE EQUINOX.

We have already taken notice of and illustrated in page 419, that apparent slow motion of the fixed stars forwards, which is caused by the like slow motion of the equinoctial points backwards; and shewn that this is owing to the revolution of the axis of the equator about the axis of the ecliptic, the pole of the equator describing in the heavens a circle about the axis of the ecliptic. By this motion they are found to recede from their ancient stations, at the rate of 50 seconds every year, making a degree in 72 years, and 25,920 years to perform one revolution.

Hence it is, that though the signs or constellations in the zodiac are called by the same names with those in the ecliptic, yet the signs in one do not answer to those in the other; the sign called Aries, for instance, in the ecliptic, is not in that part of it which answers to the figure or constel-

lation of Aries in the zodiac; the same is equally true of all the other signs. This is made very plain upon the celestial globe; for the reader will find there that the mark γ and the 30 deg. reckoned from it, which make the sign Aries in the ecliptic, are not within the figure or constellation of the ram. This motion in their longitude does not, however, vary their latitude.

Hence their places being once determined to a known year, their longitudes may be ascertained for any time past or to come, by the sole subtraction or addition of so many times 50 seconds, as there are years between that to which the given star is rectified, and that to which it is required; or knowing the quantity of precession from any former period, the distance thereof in time may be obtained, by reducing it into seconds, and dividing the result by 50, the quotient will give the number of years, as in the following examples.

EXAMPLE I.

Given, 1908 years. To find the quantity of the precession for that time.

1908

1908 years
 Multiply by - 50 seconds

60) 95400

60) 1590

Answer - - $26^{\circ} 30'$ precession in 1908 years.

EXAMPLE II.

Given, $26^{\circ} 30'$, the quantity of the precession,
 to find the time.

$26^{\circ} 30'$
 Multiply by 60

 1590 minutes

Multiply by 60

Divide by 50) 95400 seconds

Answer - 1908 years.

The regular change in the precession of the fixed stars, or rather the constant retrogression of the equinoctial points, seems to cause an irregular variation in their right ascensions and declinations, more or less, according to their distances from the pole of the ecliptic. Whence it may

not be improper to shew how these may be found, as the cosmical, achronical, and heliacal risings and settings of the fixed stars, found by the preceding problems, have respect only to the present age; and the following problem will shew the reader how to determine the ancient place of any star agreeable to the time of ancient authors, if their authority may be depended on.

P R O B L E M C V.

Given, the latitude and ancient longitude of a fixed star, to find it's right ascension and declination.

Elevate the celestial globe to $66\frac{1}{2}$ degrees, bring the pole of the ecliptic into the zenith, and there fix the quadrant of altitude; apply it's graduated edge to the given star, and it will cut it's present longitude, either on the ecliptic or broad paper circle, which in this position of the globe coincide with each other: make a mark on the quadrant, at the latitude of the given star, and remove it to it's ancient longitude, as found above; then bring the graduated edge of the moveable meridian to the mark just made upon the quadrant of altitude, and set the center of the artificial sun to that point which will then represent

sent the ancient place of the given star. That point of the moveable meridian, upon which the center of the artificial sun was placed, is it's ancient declination; and that point of the equator, cut by it's graduated edge, is it's ancient right ascension.

The globe being thus rectified to the place and precession of any particular star, as given us by ancient authors, the times of the year when such star rose or set, either cosmically, achronically, or heliacally, may be thus obtained by the preceding problems, agreeable to the period of the author under consideration. The reader, who wishes to pursue this subject further, will find it illustrated by many curious and learned examples in the Rev. Mr. Costard's History of Astronomy.

OF THE CORRESPONDENCE OF THE CELESTIAL AND TERRESTRIAL SPHERES.*

That the reader may thoroughly understand what is meant by the correspondence between the two spheres, let him imagine the celestial globe to be delineated upon glass, or any other transparent matter, which shall invest or surround the terrestrial globe, but in such a manner,

K k 4

that

* Adams's Treatise on the Globes.

that either may be turned about upon the poles of the globe, while the other remains fixed ; and suppose the first point of Aries on the investing globe to be placed upon the first point of Aries on the terrestrial globe, (which point is in the meridian of London) then every star in the celestial sphere will be directly over those places, to which it is a correspondent. Each star will then have the degree of it's right ascension directly upon the corresponding degree of terrestrial longitude ; their declination will also be the same with the latitude of the places to which they answer ; or in other words, when the declination of a star is equal to the latitude of a place, such star, within the space of 24 hours, will pass vertically over that place, and all others that have the same latitude.

If we conceive the celestial investing globe to be fixed, and the terrestrial globe to be gradually turned from west to east, it is clear, that as the meridian of London passes from one degree to another, under the investing sphere, every star in the celestial sphere becomes correspondent to another place upon the earth, and so on, until the earth has completed one diurnal revolution ; or till all the stars, by their apparent daily motion, have passed over every meridian of the
terrestrial

terrestrial globe. From this view of the subject, an amazing variety, uniting in wonderful and astonishing harmony, presents itself to the attentive reader; and future ages will find it difficult to investigate the reasons that should induce the present race of astronomers to neglect a subject so highly interesting to science, even in a practical view, but which in theory would lead them into more sublime speculations, than any that ever yet presented themselves to their minds.

A GENERAL DESCRIPTION OF THE PASSAGE OF
THE STAR MARKED γ IN THE HEAD OF THE
CONSTELLATION DRACO, OVER THE PARALLEL
OF LONDON.

The star γ , in the head of the constellation Draco, having 51 deg. 32 min. north declination, equal to the latitude of London, is the correspondent star thereto. To find the places which it passes over, bring London to the graduated side of the brass meridian, and you will find that the degree of the meridian over London and the representative of the star, passes over from London, the road to Bristol, crosses the Severn, the Bristol channel, the counties of Cork and Kerry in Ireland, the north part of the Atlantic ocean, the Streights of Belleisle, New Britain, the
north

north part of the province of Canada, New South Wales, the southern part of Kamtschatka, thence over different Tartarian nations, several provinces of Russia, over Poland, part of Germany, the southern part of the United Provinces, when crossing the sea, it arrives again at the meridian of London.

When the said star, or any other star, is on the meridian of London, or any other meridian, all other stars, according to their declination and right ascension, and difference of right ascension, (which answers to terrestrial latitude, longitude, and difference of longitude) will at the same time be on such meridians, and vertical to such places as correspond in latitude, longitude, and difference of longitude, with the declination, &c. of the respective stars.*

From the stars, therefore, thus considered, we attain a copious field of geographical knowledge, and may gain a clear idea of the proportionable distances, and real bearings, of remote empires, kingdoms, and provinces, from our own zenith, at the same instant of time; which may be found
in

* Fairman's Geography.

in the same manner as we found the place to which the sun was vertical at any proposed time.

Many instances of this mode of attaining geographical knowledge, may be found in my father's treatise on the globes.

O F T H E

U S E

O F T H E

T E R R E S T R I A L G L O B E ,

W H E N M O U N T E D I N T H E C O M M O N M A N N E R .

ALTHOUGH I have, in the first part of this essay, laid before my readers the reasons which induce me to prefer my father's manner of mounting the globes, to the old or Ptolemaic form, yet as many may be in possession of globes mounted in the old form, and others may have been taught by those globes, I thought it would render these essays more complete, to give an account of so many of the leading problems, solved on the common globes, as would enable them to apply the remainder of those here-

tofore

tofore solved, to their own use. This is the more expedient, as since the publication of my father's treatise, there have been a few attempts to do away some of the inconveniences of the ancient form, particularly that of the old hour circle, which is now generally placed under the meridian.

I cannot, however, refrain from again observing to the pupil, that the solution of the problems on the old globes depends upon appearances; that therefore, if he means to content himself with the mere mechanical solution of them, the Ptolemaic globes will answer his purpose; but if he wishes to have clear ideas of the rationale of those problems, he must use those mounted in my father's manner.

The celestial globe is used the same way in both mountings, excepting, that in my father's mounting it has some additional circles; but the difference is so trifling, that it is presumed the pupil can find no difficulty in applying the directions there as given to the old form.

P R O B L E M I.

To find the latitude and longitude of any given place on the globe.

Bring the place to the east side of the brass meridian, then the degree marked on the meridian over it shews it's latitude, and the degree of the equator, under the meridian, shews it's longitude.

Hence, if the longitude and latitude of any place be given, the place is easily found, by bringing the given longitude to the meridian; for then the place will lie under the given degree of latitude upon the meridian.

P R O B L E M II.

To find the differences of longitude between any two given places.

Bring each of the given places successively to the brazen meridian, and see where the meridian cuts the equator each time; the number of degrees contained between those two points, if it be less than 180 deg. otherwise the remainder to

360 deg. will be the difference of longitude required.

P R O B L E M I I I .

To rectify the globe for the latitude, zenith, and sun's place.

Find the latitude of the place (by prob. I.) and if the place be in the northern hemisphere, elevate the north pole above the horizon, according to the latitude of the place. If the place be in the southern hemisphere, elevate the south pole, above the south point of the horizon, as many degrees as are equal to the latitude.

Having elevated the globe according to it's latitude, count the degrees thereof upon the meridian from the equator towards the elevated pole, and that point will be the zenith, or the vertex of the place; to this point of the meridian fasten the quadrant of altitude, so that the graduated edge thereof may be joined to the said point.

Having brought the sun's place in the ecliptic to the meridian, set the hour index at twelve at noon,

noon, and the globe will be rectified to the sun's place.

PROBLEM IV.

The hour of day at any place being given, to find all those on the globe, where it is noon, midnight, or any given hour at that time.

On the globes, when mounted in the common manner, it is now customary to place the hour circle under the north pole; it is divided into twice twelve hours, and has two rows of figures, one running from east to west, the other from west to east; this circle is moveable, and the meridian answers the purpose of an index.

Bring the given place to the brazen meridian, and the given hour of the day on the hour circle; this done, turn the globe about, till the meridian points at the hour desired; then, with all those under the meridian, it is noon, midnight, or any given hour at that time.

P R O B L E M V.

The hour of the day at any place being given, to find the correspondent hour (or what o'clock it is at that time) in any other place.

Bring the given place to the brazen meridian, and set the hour circle to the given time; then turn the globe about, until the place where the hour is required comes to the meridian, and the meridian will point out the hour of the day at that place.

Thus, when it is noon at London, it is

		H.	M.	
At	Rome - -	0	52	P. M.
	Constantinople	2	7	P. M.
	Vera Cruz -	5	30	A. M.
	Pekin in China -	7	50	P. M.

P R O B L E M VI.

The day of the month being given, to find all those places on the globe where the sun will be vertical, or in the zenith that day.

Having found the sun's place in the ecliptic for the given day, bring the same to the brazen
 Ll meridian,

meridian, observe what degree of the meridian is over it, then turn the globe round it's axis, and all places that pass under that degree of the meridian will have the sun vertical, or in the zenith that day, i. e. directly over the head of each place at it's respective noon.

P R O B L E M VII.

A place being given in the torrid zone, to find those two days of the year on which the sun will be vertical to that place.

Bring the given place to the brazen meridian, and mark the degree of latitude that is exactly over it on the meridian; then turn the globe about it's axis, and observe the two points of the ecliptic, which pass exactly under that degree of latitude, and look on the horizon for the two days of the year in which the sun is in those points or degrees of the ecliptic, and they are the days required; for on them, and none else, the sun's declination is equal to the latitude of the given place.

P R O B L E M V I I I .

To find the antœci, periœci, and antipodes of any given place.

Bring the given place to the brazen meridian, and having found it's latitude, keep the globe in that position, and count the same number of degrees of latitude on the meridian, from the equator towards the contrary pole, and where the reckoning ends, that will give the place of the antœci upon the globe. Those who live at the equator have no antœci.

The globe remaining in the same position, bring the upper XII on the horary circle to the meridian, then turn the globe about till the meridian points to the lower XII; the place which then lies under the meridian, having the same latitude with the given place, is the periœci required. Those who live at the poles, if any, have no periœci.

As the globe now stands (with the index at the lower XII, the antipodes of the given place are under the same point of the brazen meridian where it's antœci stood before.

P R O B L E M IX.

To find at what hour the sun rises and sets any day in the year; and also upon what point of the compass.

Rectify the globe for the latitude of the place you are in; bring the sun's place to the meridian, and bring the XII to the meridian; then turn the sun's place to the eastern edge of the horizon, and the meridian will point out the hour of rising; if you bring it to the western edge of the horizon, it will shew the setting.

Thus on the 16th day of March, the sun rose a little past six, and set a little before six.

Note: In the summer the sun rises and sets a little to the northward of the east and west points, but in winter, a little to the southward of them. If, therefore, when the sun's place is brought to the eastern and western edges of the horizon, you look on the inner circle, right against the sun's place, you will see the point of the compass upon which the sun rises and sets that day.

P R O B L E M X.

To find the length of the day and night at any time of the year.

Only double the time of the sun's rising that day, and it gives the length of the night; double the time of his setting, and it gives the length of the day.

This problem shews how long the sun stays with us any day, and how long he is absent from us any night.

Thus on the 26th of May the sun rises about four, and sets about eight; therefore, the day is sixteen hours long, and the night eight.

P R O B L E M XI.

To find the length of the longest or shortest day, at any place upon the earth.

Rectify the globe for that place, bring the beginning of Cancer to the meridian; bring XII to the meridian, then bring the same degree of Cancer to the east part of the horizon, and the meridian will shew the time of the sun's rising.

If the same degree be brought to the western side, the meridian will shew the setting, which doubled (as in the last problem) will give the length of the longest day and shortest night.

If we bring the beginning of Capricorn to the meridian, and proceed in all respects as before, we shall have the length of the longest night and shortest day.

Thus in the Great Mogul's dominions, the longest day is 14 hours, and the shortest night 10 hours. The shortest day is 10 hours, and the longest night 14 hours.

At Peterburgh, the seat of the Empress of Russia, the longest day is about $19\frac{1}{2}$ hours, and the shortest night $4\frac{1}{2}$ hours; the shortest day $4\frac{1}{2}$ hours, and longest night $19\frac{1}{2}$ hours.

Note: In all places near the equator, the sun rises and sets at six the year round. From thence to the polar circles, the days increase as the latitude increases; so that at those circles themselves, the longest day is 24 hours, and the longest night just the same. From the polar circles to the poles, the days continue to lengthen into weeks and months; so that at the very pole,

the sun shines for six months together in summer, and is absent from it six months in winter.

Note: That when it is summer with the northern inhabitants, it is winter with the southern, and the contrary; and every part of the world partakes of an equal share of light and darkness.

P R O B L E M X I I .

To find all those inhabitants to whom the sun is this moment rising or setting, in their meridian or midnight.

Find the sun's place in the ecliptic, and raise the pole as much above the horizon as the sun (that day) declines from the equator; then bring the place where the sun is vertical at that hour to the brass meridian; so will it then be in the zenith or center of the horizon. Now see what countries lie on the western edge of the horizon, for in them the sun is rising; to those on the eastern side he is setting; to those under the upper part of the meridian it is noon day; and to those under the lower part of it, it is midnight.

Thus on the 25th of April, at six o'clock in the evening, at Worcester,

The sun is rising at New Zealand; and to those who are sailing in the middle of the Great South Sea.

The sun is setting at Sweden, Hungary, Italy, Tunis, in the middle of Negroland and Guinea.

In the meridian (or noon) at the middle of Mexico, Bay of Honduras, middle of Florida, Canada, &c.

Midnight at the middle of Tartary, Bengal, India, and the seas near the Sunda isles.

P R O B L E M XIII.

To find the beginning and end of twilight.

The twilight is that faint light which opens the morning by little and little in the east, before the sun rises; and gradually shuts in the evening in the west, after the sun is set. It arises from the sun's illuminating the upper part of the atmosphere, and begins always when he approaches within

within 18 degrees of the eastern part of the horizon, and ends when he descends 18 degrees below the western ; when dark night commences, and continues till day breaks again.

To find the beginning of twilight, rectify the globe ; turn the degree of the ecliptic, which is opposite to the sun's place, till it is elevated 18 degrees in the quadrant of altitude above the horizon on the west, so will the index point the hour twilight begins.

This short specimen of problems by the old globes, it is presumed, will be sufficient to enable the pupil to solve any other.

E S S A Y III.

P A R T I.

E S S A Y III.

P A R T I.

A DESCRIPTION OF
SEVERAL INSTRUMENTS,
WHICH ARE DESIGNED TO ILLUSTRATE THE
GENERAL PRINCIPLES OF ASTRONOMY.

IN pursuance of my original plan, I proceed to describe those instruments that have been contrived to facilitate the progress of astronomy and geography. By their assistance, the lecturer and teacher are enabled to impress more strongly on their pupils, the principles designed to be cultivated. The pupil, by resolving a problem, or explaining any particular phænomenon by an instrument, strengthens the faculties of his mind,
and

and realizes to himself by the eye and the touch, what would otherwise have left but a faint and imperfect trace upon his memory.

To represent by machines the motion and various aspects of the heavenly bodies, to shew by them the parallelism of the earth's axis, together with it's diurnal and annual motions ; and by this means to explain the beautiful variety of the seasons, and other celestial and terrestrial phænomena, has ever been considered as one of the noblest efforts of mechanical genius.

It is the business of this essay to describe the most modern instruments that have been contrived for this purpose. But among the various methods that have been imagined, to exhibit to the uninformed eye the motion of the heavenly bodies, there is none whose effect is so striking as the Eidouranion of Mr. Walker ; and I must own, I do not remember ever to have received more pleasure than I did upon seeing the curtain draw up, and beholding the planetary bodies in motion, in this beautiful machine. A description of it does not come within the limits of this essay, as it's effects are only striking when it is made upon a very large scale.

The three first that I shall describe are represented in plate V. plate XV. and plate XVI: the one is a manual planetarium, the other a simple tellurian, the third a lunarium: these three ought to accompany every pair of globes; they are rendered as simple as possible, in order to reduce the price, that much real knowledge may be attained at an easy rate.

Plate XVII. fig. 1, and plate XVIII. fig. 1 and 2, represent what I deem to be the completest instrument of the kind: it is so contrived as to exhibit, with the greatest accuracy and perspicuity, the phænomena of the earth and heavens; being the most comprehensive, and at the same time the least defective.

Plate XIX. represents an elegant and neat planetarium, tellurian, and lunarium, in one instrument, the whole moving by wheel-work.

Fig. 1 and 2, plate XIII. two armillary spheres; a planetarium is included in that of fig. 1, plate XIII. fig. 2 is an armillary sphere, by which the real and apparent motion of the earth and heavens may be illustrated and explained.

A DESCRIPTION OF THE THREE INSTRUMENTS
REPRESENTED IN PLATE V. PLATE XV. AND
PLATE XVI.

In this part we shall suppose the reader to be acquainted with those definitions that we have had occasion to introduce in the preceding parts of this work ; these being remembered, he will meet with little or no difficulty in the following pages.

Plate XV. represents a manual planetarium, or one in which the planets must be moved by hand, without the assistance of wheel-work.

FIRST. A DESCRIPTION OF THE PLANETARIUM,
REPRESENTED AT PLATE XV.

A planetarium may be considered as a diametrical section of our universe, in which the upper and lower hemispheres are suppressed : the sun is represented by a brass ball ☉ placed in the center of the instrument ; round about, but at different distances, the planets are placed thus on the stem ; near the sun is Mercury ☿, then Venus ♀, the Earth ⊕, Mars ♂, Jupiter ♃, and lastly Saturn ♄.

The

The secondary ones are placed about the primary ones ; thus about the earth there is one little ball to represent the moon, about Jupiter four, and about Saturn are five besides his ring.

Upon the plate of the planetarium are placed, in two opposite circles, the ecliptic, and the calendar of months, by which means the planets may be set to their mean places in the ecliptic for any day of the year.

Imperfect as this instrument may appear, it will greatly assist the tutor in communicating to his pupil general ideas of the order, number, phases, relative positions, and motion of the celestial bodies.

You may turn either of the planets round by laying hold of, and removing the brass bar which supports them. In thus imitating their different revolutions, it will be very obvious that if each of them left a trace behind of their motions, there would be fix concentric circles described about the brass ball representing their different orbits.

A second observation may be very properly that, which has been insisted on in the first essay

of this work, page 17, namely, that the motions of the planets are regular and harmonious as seen from the sun; the pupil, by supposing himself situated on the brass ball, and viewing the motion of the planets from thence, will find the idea pleasingly and fully illustrated.

Let him afterwards suppose himself to be situated on the earth, and he will soon find, that it is his situation which is the source of apparent irregularity. If he considers the motions of the planets Venus and Mercury, he will find that in one part of their orbit, they pass between us and the sun: this is called their inferior conjunction, while in the opposite part they pass on beyond, or on the other side of the sun, which is called their superior conjunction.

Here also it becomes very evident, that neither of these planets can ever appear at a great distance from the sun. The tutor may easily explain this, and what is also meant by the elongation of a planet, by applying the doubled end of a piece of thread to the globe that represents the earth; one of the ends of the thread close to the stem of the sun, and the other end to that of Venus and Mercury; he will then find on moving the planets round, that they can never appear
far

far from the sun, and that Mercury recedes less from him than Venus; the angle observed by this means would coincide exactly with that of the heavens, if the arms of the planetarium were at a sufficient length to represent the proportional distances of the planets from each other. It is because Mercury removes so little from the sun, that he is so seldom seen.

The pupil will find that the superior planets, Mars, Jupiter, or Saturn, are sometimes seen in direct opposition to the sun, having the earth between them and it; they are at other times seen in conjunction with the sun, or on the contrary side of it.

The phases of the planets are illustrated by placing a small lamp, or a piece of candle, in the center of the machine, instead of the brass ball that represents the sun.

The planets when moving, are continually varying their distances from the earth, and consequently cannot appear to move with an uniform velocity; for they will be seen to move fastest when they are nearest the earth, and slowest when they are most remote from it; hence also

they appear much larger at one time than at another.

The teacher may by this instrument make it obvious to his pupil, why the planets appear to move sometimes direct, at others stationary or retrograde ; by extending a string from the earth over either of the planets, and to some distance beyond them, and keeping it over them during a revolution.

By the planetarium, the pupil will receive the most satisfactory evidence of the truth of the Copernican, and the errors of the Ptolemaic system. For on removing the brass ball from the center, and placing in it's stead a small ivory one to represent the earth, and placing a small brass ball instead of the ivory earth, the instrument will then exhibit the situation of the planetary bodies according to the Ptolemaic system.

It is plain, that in this system, in which the earth is made the center of the motion of the heavenly bodies, 1. That their motions would all have been the same way, or from west to east continually ; whereas in the heaven they are seen to move sometimes from west to east, at others
from

from east to west, while at other times they are stationary. 2. They would in this case appear to move with an uniform velocity; whereas they are always observed to move with a variable one. 3. On the supposition that the earth was the center of the system, it is evident from the instrument, that any of the planets might be seen at all distances from the sun, or that Mercury or Venus might be seen when the sun is setting, not only in the south, but even in the east, situations in which they were never seen by any observer. 4. The planets Venus and Mercury being, according to this hypothesis, within the orbit of the sun, could never be seen to go behind or beyond; but from observation we find them as often behind as before the sun. To remedy these imperfections in his system, and reconcile it with nature, Ptolemy was obliged to introduce various circles, into which he supposed the planets to deviate in their revolutions round the earth; thus multiplying causes without necessity, and rendering that perplexed, which, when rightly considered, is found to be simple.

DESCRIPTION OF THE TELLURIAN REPRESENTED
AT FIG. I, PLATE V.

This is the most simple tellurian that is made ; my endeavours in constructing it have been to form an instrument that should render the phenomena of the seasons clear to the youngest pupil.

It consists of four small globes, A, B, C, D, designed to represent our earth at the four principal seasons of the year, summer and winter, spring and autumn. These globes are all inclined in an angle of $66\frac{1}{2}$ degrees to the plane of the ecliptic ; in the center of the instrument a brass ball is placed, to represent the sun ; there is also a small pillar, on the top of which are placed several wires, parallel to each other, to represent parallel rays proceeding from the sun ; to each globe there is a black hemisphere, placed opposite to the sun, dividing the enlightened from the unenlightened parts of the globe ; one of these black hemispheres may be taken off occasionally, and the globe be removed from it's situation. There is also a circle, which is not represented in the plate ; this circle is placed at the height of the earth's center, and is intended to represent the orbit of the earth ; four pieces of wire are placed at the four quarters of this circle, having the

same

same inclination to it that the axis of the earth has to the plane of it's orbit, to give a clear idea of what is meant by the inclination of the axis of the earth, and what by it's parallelism.

To explain the required phænomena by this instrument, the tutor has only to assume two propositions: 1. That a globular luminous body sending out parallel rays, will only enlighten one half of another globe, and consequently that hemisphere only is illuminated which is turned towards the luminous body. 2. That the globe moves round the luminous body in such a manner, that in all parts of it's orbit, it's axis may be parallel to itself, and have a certain inclination to the plane of the orbit.

When the earth is in the first point of Capricorn, the sun will appear in the first point of Cancer; in this situation, which is that of the ball A, fig. 1, plate V. the north pole is turned towards the sun, and that part of the globe situated within the arctic circle, lies wholly in the enlightened hemisphere, and has no night; while the south pole, and it's polar circle, being totally turned from the sun, are quite involved in darkness.

In this position of the earth, the inhabitants of the northern hemisphere will have their days at the longest, and their nights at the shortest; and the length of the longest days are greater, according as the place is further removed from the equator, till it reaches the polar circle, from whence to the pole there is at this season continual day, and the season is that of summer: while all the inhabitants on the south side of the equator will have their nights the longest, and their days the shortest; because the greatest portion of the parallels which they describe by the diurnal motion of the earth, are in darkness, and the least in the light; the season of the year to them at this time is winter.

To render this subject clearer to the pupil, let the tutor now refer him to the opposite situation of the globe at C, when the earth is in the first point of Cancer, and the sun is seen in the first point of Capricorn. Here the northern polar circle is all involved in darkness, and has no day; while the southern is entirely within the light, and to the inhabitants thereof there is no night. It is now winter in the northern hemisphere, and the days are shorter than the night; while in the southern hemisphere, the days are at the longest. If the hemisphere be now removed
from

from the globe which is at Capricorn, and the globe itself be taken out, and brought near to that at Cancer, keeping the axis parallel to it's former situation, the young mind will immediately perceive how the beautiful vicissitude in the seasons is effected, merely by the inclination of the earth's axis to the plane of it's orbit, and the parallelism of it's axis during it's annual course.

When the globe is at the first point of Aries, as at D, and the sun appears to be in the first point of Libra; the circle of illumination touches both poles, and the sun is vertical to the equator; the axis inclines sideways to the sun, so that the earth is enlightened from pole to pole, and the days and nights are equal at all places of the earth, and the season is that of the vernal equinox.

When the earth is at Libra, the sun appears in Aries; the earth is again enlightened from pole to pole, and the days and nights are again every where equal.

As there are 24 meridian semicircles drawn on each of the globes, all meeting at their poles, and as one rotation of the earth on it's axis is performed in 24 hours, each of these meridians

is an hour distant from the other in every parallel of latitude. You may, therefore, find how long the day is at any place of the earth, in either of the four situations, by counting how many of these meridians are in the light in the parallel of latitude of the given place; this number being subtracted from 24 hours, will give the length of the night.

In all positions of the earth, half the equator is always in the light, and half in darkness; therefore, at the equator the days and nights are all equal.

If you take off the cap of the globe which is moveable, then remove it from its place, and hold it in the four cardinal situations in which the others are fixed, but with the axis perpendicular to the plane of the ecliptic; you will find that the seasons would, in this case, have been always the same, without any alteration, and the days and nights of the same length at all places, throughout the whole year: only at the poles there would be hardly either day or night, the sun neither rising above, nor setting below the horizon, but going round the same continually, with one-half of his disc in view. This is what would really happen,

happen, if the axis of the earth did not incline to the plane of it's orbit.

DESCRIPTION OF THE LUNARIUM, WHICH IS
REPRESENTED AT FIG. I, PLATE XVI.

A B is the base of the instrument, on which there are two circles, one with the signs of the ecliptic, the other with the days of the month corresponding thereto, for the reader setting the moon or her nodes to their respective places.

C D E F an inclined brass plane, G H I K another plane parallel to the former, and supported by two brass props; the inner edge of this ring nearly touches the artificial moon, and represents the plane of the moon's orbit.

The moon is sometimes on the north side, and sometimes on the south side of the ecliptic, which is called her latitude; the degrees and parts thereof are engraved from each node to the highest and lowest part of her orbit, which is 5 deg. 18 min. on each side of the nodes.

The two nodes lie in the plane of the ecliptic, in those parts of the moon's orbit where the wires that support it are fixed. That from which
the

the moon begins to ascend northward, above the ecliptic, is called the ascending or north node, as the opposite one from which the moon descends southward, below the ecliptic, is called her descending node. They always keep opposite to each other, and move backward through all the signs of the ecliptic, in about nineteen years; on each side of them both is engraved a small sun at 18 degrees, and a small moon 12 degrees distant from them; these are the limits of eclipses, the first of the sun, and the other of the moon. In using this instrument, the brass ball representing the sun, is supposed to be on the table, opposite to it's place in the ecliptic, for the given time; and that the moon's nodes are also set to their place in the ecliptic.

If the moon's orbit coincided with the plane of the ecliptic, there would be an eclipse of the sun at every new moon; because the moon's shadow then passing over some parts of the earth, would deprive them of the sun's light; but because the sun is a great luminous body, and the moon a small opake one, her shadow will be conical, and can only cover a small part of the earth at once; and therefore there would be several such eclipses invisible, though at noon day, to a great many places on the earth. The
moon

moon would also, every time she was opposite to the sun, pass through the shadow of the earth, and undergo a total eclipse to all those inhabitants of the earth to whom it was visible.

But as the sun and the earth are always in the plane of the ecliptic, and the moon's orbit is inclined to it, and cuts it only in the nodes, it is plain there can be no eclipses, but when a right line passing through the nodes would, if continued, run either through, or nearly by the sun, at the time of new or full moon; and from the time that this happens till it does so again, is about 173 days, or near half a year, save what allowance is to be made of 18 degrees on either side of the nodes, within which the sun may be eclipsed; and of 12 degrees, within which the moon may suffer an eclipse.

The foregoing circumstances are rendered evident to the senses and the mind, by means of the lunarium; particularly so, when a candle, or lamp, is substituted in the place of the brass sun fig. 2.

O F T H E

U S E A N D A P P L I C A T I O N

O F T H E M O S T I M P R O V E D

P L A N E T A R I U M , L U N A R I U M ,

A N D

T E L L U R I A N .

THE description of the preceding instruments is in a great degree applicable to this improved planetarium ; but as the construction of this is more perfect, and as it is also more extensive in it's use, a fuller description is necessary, which I give the more readily, as the description of this will serve, with very few alterations, for the greater part of orreries, &c.

It seems highly probable, that the ancients were not unacquainted with planetary machines,
and

and that the same powers of genius which led them to contemplate and reason upon the motion of the heavenly bodies, induced them to realize their ideas, and form instruments for explaining them; and we may fairly presume, that these were carried to no small degree of perfection, when we consider that of one Archimedes was the maker, and Cicero the encomiast.

The instrument now to be described, was invented by the celebrated HUYGENS; though since his time it has been ascribed to almost as many inventors as makers; each deviation in form, the mounting it in this mode or the other, the addition of a zodiac, or some such slight changes, have been deemed by many of sufficient importance to give them a claim to the title of inventors;—be it so. Let the friend of science encourage every humble effort to improve it, and let him bestow a name which, though it may in some measure gratify vanity, yet incites to labour, rather than by contempt check the ardour, or discourage the talents which, when called forth, may be of the greatest service to society.

Fig. 1, plate XVII. represents the planetarium, the box in which the wheel-work is contained

contained that moves the fix primary planets round the sun, in their proper periods of time, this motion being communicated to them by turning the handle.

On the upper plate of the planetarium, there are placed in two opposite circles, corresponding to each other, the signs of the ecliptic, and the days of the month, by means whereof the planets may be easily set to their mean places in the ecliptic for any day in the year.

Through the center of the plate there passes a strong stem, on which the brass ball \odot is placed, which represents the sun; round the stem are the different sockets, which carry the arms, by which the balls representing the planets are supported.

The planets are ivory balls, having the hemisphere which is next the sun white, the other black, to exhibit their respective phases to each other. The planets may be easily put on or taken off their sockets, as occasion requires.

About the primary planets are placed the secondary planets, or moons, which are in this
instru-

instrument only moveable by hand; but when the instrument is fitted up on a large scale, and in a more expensive form, even these are put in motion by the wheel-work.

The planets are disposed in the following order: in the center is the brass ball \odot to represent the sun, then Mercury ☿ , Venus ♀ , the earth \oplus , Mars ♂ , Jupiter ♃ , and Saturn ♄ ; the Georgium Sidus is not inserted, because it would not only enhance the expence, but it's motion would be so slow, as to render it incapable of affording either amusement or instruction. By turning the handles, they all move about the sun from west to east, with the same relative velocities and periodical times that they have in the heavens.

When the pupil has been gratified by putting the instrument in motion, and making his own observations on those motions, it will be proper to acquaint him with the names of the different planets, and of their division into primary and secondary, to shew him how they were first distinguished from the fixed stars, and how the length of their periodic revolution was discovered. Here it will be proper to observe that the annual motion of the earth, or the time it takes to per-

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form

form it's period round the sun, is made the basis to which the others are compared; and this is one of the reasons why the months, and days of our months, are engraved on the circle. Having observed this, the planets may be put in motion, and they will be found to revolve round the representative of the sun in their proportionable times, each planet always completing it's revolution in the same space of time, in periods regulated and proportioned to their distance from the sun: the curves which they describe in their revolution, is what is termed their orbit.

In order to assist the imagination in forming an idea of the vast distances of the planets from the sun, the following suppositions have been made: That if a body projected from the sun, should fly with the swiftness of a cannon ball, that is, 480 miles every hour, this body would reach the orbit of Mercury in about 8 years, 276 days; of Venus in 16 years, 136 days; of the earth in 22 years, 226 days; of Mars in 34 years, 170 days; of Jupiter in 117 years, 234 days; and the orbit of Saturn in 215 years, 286 days.

If the reader should think this idea too extensive, he may contract it in the following manner,
in

in which the proportional bulks and distances of the sun and planets are considered.

The dome of St. Paul's is 145 feet in diameter. Suppose a globe of this size to represent the sun, then a globe of $9\frac{7}{15}$ inches will represent Mercury; one of $17\frac{2}{5}$ inches Venus; one of 18 inches the earth; one of 5 inches diameter the moon; one of 10 inches Mars; one of 15 feet Jupiter; one of $11\frac{1}{2}$ Saturn, with his ring 4 feet broad, and at the same distance from his body all around.

In this proportion, suppose the sun to be at St. Paul's, Mercury might be at the Tower of London, Venus at St. James's palace, the earth at Mary-le-bone, Jupiter at Hampton-Court, and Saturn at Cliefden.*

As the general phænomena of the planetary system will be best understood by an induction of particulars, I should advise the tutor to remove all the planets but those whose motion he is going to explain. For instance, let us suppose him to leave only the earth, Mars, and Venus. Now as each planet moves with a different degree of velocity,

N n 2

they

* Ferguson's Tables and Tracts, p. 126.

they are continually changing their relative positions. Thus on turning the handle of the machine, he will find, 1st, that the earth moves twice as fast as Mars, making two revolutions while he makes one; and Venus, on the other hand, moves much faster than the earth. Secondly, that in each revolution of the earth these planets continually change their relative positions, corresponding some times with the same point of the ecliptic, but much oftener with different points.

We may now proceed to make some observations on the motions of Venus, as observed in the planetarium. If considered as viewed from the sun, we shall find that Venus would appear at one time nearer to the earth than at another; that sometimes she would appear in the same part of the heavens, and at others in opposite parts thereof.

As the planets, when seen from the sun, change their position with respect to the earth, so do they also, when seen from the earth, change their position with respect to the sun, being sometimes nearer to, at others farther from, and at times in conjunction with him.

But

But the conjunctions of Venus or Mercury, seen from the earth, not only happen when they are seen together from the sun, but also when they appear to be in opposition to the solar spectator. To illustrate this, bring the earth and Venus to the first point of Capricorn; then by applying a string from the sun over Venus and the earth, you will find them to be in conjunction, or on the same point of the ecliptic.

Whereas if you turn the handle till the sun is between Venus and the earth, a spectator in the sun will see Venus and the earth in opposition; but an inhabitant of the earth will see Venus, not in opposition to the sun, but in conjunction with him.

In the first conjunction Venus is between the sun and earth; this is called the inferior conjunction. In the second, the sun is situated between the earth and Venus; this is called the superior conjunction.

After either of these conjunctions, Venus will be seen to recede daily from the sun, but never departing beyond certain bounds, never appearing opposite to the sun; and when she is seen at the greatest distance from him, a line joining

her center with the center of the earth, will be a tangent to the orbit of Venus.

To illustrate this, take off the sun from it's support, and the ball of Venus from it's supporting stem; place the wire, fig. 2, plate XVII. so that the part P may be on the stem that supports the earth, and a similar socket, fig. 3, on the pin which supports the ball of Venus; the wire F is to lie in a notch at the top of the socket, which has been put upon the supporting stem of Venus; then will the wire represent a visual ray going from an inhabitant of the earth to Venus. By turning the handle, you will now find that the planet never departs further than certain limits from the sun, which are called it's greatest elongations, when the wire becomes a tangent to the orbit; after which, it approaches the sun, till it arrives at either the inferior or superior conjunction.

It will also be evident from the instruments, that Venus, from her superior conjunction, when she is furthest from the earth, to the time of her inferior conjunction, when she is nearest, sets later than the sun, is seen after sun-set, and is, as it were, the forerunner of night and darkness. But from the inferior conjunction, till she comes

the superior one, she is always seen westward of the sun, and must consequently set before him in the evening, and rise before him in the morning, foretelling that light and day are at hand.

Bring Venus and the earth to the beginning of Aries, when they will be in conjunction; and turn the handle for nearly 225 days, and as Venus moves faster than the earth, she will be come to Aries, and have finished her course, but will not have overtaken the earth, who has moved on in the mean time; and Venus must go on for some time, in order to overtake her.

Therefore, if Venus should be this day in conjunction with the sun, in the inferior part of her orbit, she will not come again to the same conjunction till after 1 year, 7 months, and 12 days.

It is also plain, by inspection of the planetarium, that though Venus does always keep nearly at the same distance from the sun, yet she is continually changing her distance from the earth; her distance is greatest when she is in her superior, and least when she is in her inferior conjunction.

As Venus is an opake globe, and only shines by the light she receives from the sun, that face which is turned towards the sun will always be bright, while the opposite one will be in darkness; consequently, if the situation of the earth be such, that the dark side of Venus be turned towards us, she will then be invisible, except she appear like a spot on the disk of the sun. If her whole illuminated face is turned towards the earth, as it is in her superior conjunction, she appears of a circular form, and according to the different positions of the earth and Venus, she will have different forms, and appear with different phases, undergoing the same changes of form as the moon. These different phases are seen very plain in this instrument, as the side of the planet which is opposite to the sun, is blackened; so that in any position, a line drawn from the earth to the planet, will represent that part of her disk which is visible to us.

The irregularities in the apparent motions of the planets, is a subject that this instrument will fully elucidate; and the pupil will find that they are only apparent, taking their rise from the situation and motion of the observer. To illustrate this, let us suppose the above-mentioned wire, when connected with Venus and the earth, to be

be the visual ray of an observer on the earth, it will then point out how the motions of Venus appear in the heavens, and the path she appears to us to describe among the fixed stars.

Let Venus be placed near her superior conjunction, and the instrument in motion, the wire will mark out the apparent motion of Venus in the ecliptic. Thus Venus will appear to move eastward in the ecliptic, till the wire becomes a tangent to the orbit of Venus, in which situation she will appear to us to be stationary, or not to advance at all among the fixed stars; a circumstance which is exceeding visible and clear upon the planetarium.

Continue turning, till Venus be in her superior conjunction, and you will find by the wire, or visual ray, that she now appears to move backward in the ecliptic, or from east to west, till she is arrived to that part where the visual ray again becomes a tangent to her orbit. In which position, Venus will again appear stationary for some time; after which, she will commence anew her direct motion.

Hence when Venus is in the superior part of her orbit, she is always seen to move directly,
according

according to the order of the signs ; but when she is in the inferior part, she appears to move in a contrary direction.

What has been said concerning the motions of Venus, is applicable to those of Mercury ; but the conjunctions of Mercury with the sun, as well as the times of his being direct stationary or retrograde, are more frequent than those of Venus.

If the tutor wishes to extend his observations on the instrument to Mars, he will find by the visual ray, that Mars, when in conjunction, and when in opposition, will appear in the same point of the ecliptic, whether it is seen from the sun or the earth ; and in this situation only is it's real and apparent place the same, because then only the ray proceeds as if it came from the center of the universe.

He will observe, that the direct motion of the superior planets is swifter the nearer it is to the conjunction, and slower when it is nearer to quadrature with the sun ; but that the retrograde motion of a superior planet is swifter the nearer it is to opposition, and slower the nearer it is to quadrature.

quadrature ; but at the time of change from direct to retrograde, it's motion becomes insensible.

Of all the prejudices which philosophy contradicts, there is none so general as that the earth keeps it's place unmoved. This opinion seems to be universal, till it is corrected by instruction, or by philosophical speculation. Those who have any tincture of education, are not now in danger of being held by it ; but they find at first a reluctance to believe that there are antipodes, that the earth is spherical, and turns round it's axis every day, and round the sun every year. They can recollect the time when reason struggled with prejudice upon these points, and prevailed at length, but not without some efforts.*

The planetarium gives ocular demonstration of the motion of the earth about the sun, by shewing that it is thus only that the celestial phænomena can be explained, and making the absurdity of the Ptolemaic system evident to the senses of young people. For this purpose, take off the brass ball which represents the sun, and put on the small ivory ball which accompanies the instrument in it's place, to represent
the

* Reid's Essays on the Intellectual Powers of Man.

the earth, and place a small brass ball for the sun, on that arm which carries the earth.

The instrument in this state will give an idea of the Ptolemaic system, with the earth immoveable in the center, and the heavenly bodies revolving about in the following order : Mercury, Venus, THE SUN, Mars, Jupiter, and Saturn. Now in this disposition of the planets, several circumstances are to be observed, that are contrary to the real appearances of the celestial motions, and which therefore prove the falsity of this system.

It will appear from the instrument,* that on this hypothesis Mercury and Venus could never be seen to go behind the sun, from the earth, because the orbits of both of them are contained between the sun and the earth ; but these planets are seen to go as often behind the sun as before it ; we may, therefore, from hence conclude, that this system is erroneous.

It is also apparent in the planetarium, that on this scheme these planets might be seen in conjunction with, or in opposition to the sun, or at any distance from it. But this is contrary to experience ; for they are never seen in opposition to
to

to the sun, nor ever recede from it beyond certain limits.

Again, on the Ptolemaic system all the planets would be at an equal distance from the earth, in all parts of their orbits, and would therefore necessarily appear always of the same magnitude, and moving with equal and uniform velocities in one direction; circumstances which are known to be repugnant to observation and experience.

TO USE THE INSTRUMENT AS A TELLURIAN,
PLATE XVIII. FIG. I.

The sun, the earth, and the moon, are bodies, which, from our connection with them, are so interesting to us, that it is necessary to enter into a minute detail of their respective phænomena. To render this instrument a tellurian, all the planets are first to be taken off, the piece of wheel-work A B is to be placed on in their stead, in such a manner, that the wheel c may fall into the teeth that are cut upon the edge of the ecliptic. The milled nut D is then to be screwed on, to keep the wheel-work firmly in it's place. It is best to place this wheel-work in such a manner, that the index E may point to the first of June,
and

and then to move the globe, so that the north pole may be turned towards the sun.

The instrument is now ready to shew, in an accurate and clear manner, all the phænomena arising from the annual and diurnal motion of the earth; as the globe is of 3 inches diameter, all the continents, seas, kingdoms, &c. may be distinctly seen; the equator, the ecliptic, tropics, and other circles, are very visible, so that the problems relative to peculiar places, may be satisfactorily solved. The axis of the earth is inclined to the ecliptic in an angle of $66\frac{1}{2}$ degrees, and preserves it's parallelism during the whole of it's revolution. About the globe there is a circle, to represent the TERMINATOR, or boundary between light and darkness, dividing the enlightened from the dark hemisphere. At N O is an hour circle, to determine the time of sun rising or setting.

The brass index G represents a central solar ray; it serves to shew when it is noon, or when the sun is upon the meridian at any given place; it also shews what sign and degree of the ecliptic on the globe the sun describes on any day, and the parallel it describes.

The

The plane of the terminator H I passes through the center of the earth, and is perpendicular to the central solar ray. The index E points out the sun's place in the ecliptic of the instrument for any given day in the year.

The first thing to be done, is to rectify the tellurian; or in other words, to put the globe into a position similar to that of the earth, for any given day. Thus to rectify the tellurian for the 21st of June, turn the handle till the annual index comes to the given day; then move the globe by the arm K L, so that the north pole may be turned towards the sun; and adjust the terminator, so that it may just touch the edge of the arctic circle. The globe is then in the situation of the earth for the longest day in our northern hemisphere, the annual index pointing to the first point of Cancer and the 21st of June; bring the meridian of London to coincide with the central solar ray, and move the hour circle N O, till the index L points to XII; we then have the situation of London with respect to the longest day.

Now on gently turning the handle of the machine, the point representing London will, by the rotation of the earth, be carried away

towards the east, while the sun seems to move westward; and when London has arrived at the eastern part of the terminator, the index will point on the hour circle the time of sun-setting for that day; continue to turn on, and London will move in the shaded part of the earth, on the other side of the terminator; when the index is again at XII, it is midnight at London; by moving on, London will emerge from the western side of the terminator, and the index will point out the time of sun-rising, the sun at that instant appearing to rise above the horizon in the east, to an inhabitant of London.

It will be evident by the instrument, while in this position, that the central solar ray, during the whole revolution of the earth on it's axis, only points to the tropic of Cancer, and that the sun is vertical to no other part of the earth, but those that are under this tropic.

By observing how the terminator cuts the several parallels of the globe, we shall find that all those between the northern and southern polar circles (except the equator) are divided unequally into diurnal and nocturnal arches, the former being greatest on the north side of the equator, and the latter on the south side of it.

In this position, the northern polar circle is wholly on that side the terminator which is nearest the sun, and therefore altogether in the enlightened hemisphere, and the inhabitants thereof enjoy a continual day. In the same manner, the inhabitants of the southern polar circle continue in the dark at this time, notwithstanding the diurnal revolution of the earth; it is the annual motion only which can relieve them from this situation of perpetual darkness, and bring to them the blessings of day, and the enjoyments of summer; while in this state the inhabitants in north latitude are nearest to the central solar ray, and consequently to the sun's perpendicular beams, and of course a greater number of his rays will fall upon any given place, than at any other time; the sun's rays do now also pass through a less quantity of the atmosphere, which, together with the length of the day, and the shortness of the night, are the reasons of the increase of heat in summer, together with all its other delightful effects.

While the earth continues to turn round on its own axis once a day, it is continually advancing from west to east, according to the order of the signs, as is seen by the progress of the annual index E, which points successively to

all the signs and degrees of the ecliptic ; the sun in the mean time seems to describe the ecliptic also, going from west to east, at the distance of six signs from the earth, that is, when the earth really sets out from the first point of Capricorn, the sun seems to set out from the first point of Cancer, as is plain from the index.

But as during the annual revolution of the earth, the axis always remains parallel to itself, the situation of this axis, with respect to the sun, must be continually changing.

As the earth moves on in the ecliptic, the northern polar circle gets gradually under the terminator, so that when the earth is arrived at the first point of Aries, and the annual index is at the first point of Libra on the 22d of September, this circle is divided into two equal parts by the terminator, as is also every other parallel circle, and consequently the diurnal and nocturnal arches are equal ; this is called the time of equinox, the days and nights are then equal all over the earth, being each of them 12 hours long, as will be seen by the horary index L. The central solar ray G having successively pointed to all the parallels that may be supposed to be between the equator and the tropic of Cancer,

Cancer, is at this period perpendicular to the inhabitants that live at the equator.

By continuing to turn the handle, the earth advances in the ecliptic, and the terminator shews how the days are continually decreasing, and the diurnal arches shortening, till by degrees the whole space contained by the northern polar circle is on that side of the terminator which is opposite to the sun, which happens when the earth is got to the first point of Cancer, and the annual index is at the first point of Capricorn, on the 21st of December. In this state of the globe, the northern polar circle, and all the country within that space have no day at all; whilst the inhabitants that live within the southern polar circle, being on that side of the terminator which is next the sun, enjoy perpetual day. By this and the former situation of the earth, the pupil will observe that there are nations to whom a great portion of the year is darkness, who are condemned to pass weeks and months without the benign influence of the solar rays. The central solar ray is now perpendicular to the tropic of Capricorn; the length of the days is inversely what it was when the sun entered Cancer, the days being now at their shortest, and the nights longest in the northern hemisphere;

O o 2

the

the length of each is pointed out by the horary index.

The earth being again carried on till it enters Libra, and the sun Aries, we shall again have all the phænomena of the equinoctial seasons. The terminator will divide all the parallels into two equal parts; the poles will again be in the plane of the terminator, and consequently as the globe revolves, every place from pole to pole will describe an equal arch in the enlightened and obscure hemispheres, entering into and going out of each exactly at six o'clock, as shewn by the hour index.

As the earth advances, more of the northern polar circle comes into the illuminated hemisphere, and consequently the days increase with us, while those on the other side the equator decrease, till the earth arrives at the first point of Capricorn, the place from which we first began to make our observations.

Take off the globe and it's terminator, and put on in it's place the globe which accompanies the instrument, and which is furnished with a meridian, horizon, and quadrant of altitude; the edge of the horizon is graduated from the east
and

and west, to the north and south points, and within these divisions are the points of the compass to the under side of this horizon ; but at 18 degrees from it another circle is affixed, to represent the twilight circle ; the meridian is graduated like the meridian of a globe ; the quadrant of altitude is divided into degrees, beginning at the zenith, and finishing at the horizon.

This globe, if the horizon be differently set with respect to the solar ray, will exhibit the various phænomena arising from the situation of the horizon with respect to the sun, either in a right, a parallel, or an oblique sphere ; or having set the horizon to any place, you will see by the central solar ray how long the sun is above or below the horizon of that place, and at what point of the compass he rises, his meridian altitude, and many other curious particulars, of which we shall give a few examples.

Set the horizon to coincide with the equator, and place the earth in the first point of Libra ; then will the globe be in the position of a parallel sphere, and of the inhabitants of the poles at that season of the year, which inhabitants are represented by the pin at the upper part of the quadrant of altitude ; the handle being turned

O o 3

round

round gently, the earth will revolve upon it's axis, and the solar ray will coincide with the horizon, without deviating in the least to the north or south; shewing, that on the 21st of March the sun does not appear to rise or set to the terrestrial poles, but passes round through all the points of the compass, the plane of the horizon bisecting the sun's disk.

Now place the horizon, so that it may coincide with the poles, and the pin representing an inhabitant be over the equator, the globe in this position is said to be in that of a right sphere; the equator, and all the parallels of latitude, are at right angles, or perpendicular to the horizon; by turning the handle till the earth has completed a year, or one revolution about the sun, we shall perceive all the solar phænomena as they happen to an inhabitant at the equator, which are,
1. That the sun rises at six, and sets at six, throughout the year, so that the days and nights there are perpetually equal. 2. That on the 21st of March, and 22^d of September, the sun is in the zenith, or exactly over the heads of the inhabitants. That one half of the year between March and September, the sun is every day full north, and the other half between September
and

and March, is full south of the equator, his meridian altitude being never less than $66\frac{1}{2}$ degrees.

If the pin representing an inhabitant be now removed out of the equator, and set upon any place between it and the poles, the horizon will not then pass through either of the poles, nor coincide with the equator, but cut it obliquely, one-half being above, the other half below the horizon; the globe in this state is said to be in that of an oblique sphere, of which there are as many varieties as there are places between the equator and either pole. But one example will be sufficient; for whatever appearance happens to one place, the same, as to kind, happens to every other place, differing only in degree, as the latitudes differ. Bring the pin, therefore, over London, then will the horizon represent the horizon of London, and in one revolution of the earth round the sun, we shall have all the solar appearances through the four seasons clearly exhibited, as they really are in nature; that is, the earth standing at the first degree of Libra, and the sun then entering into Aries, the meridian turned to the solar ray, and the hour index set to XII, you will then have the globe standing in the same position towards the sun, as our earth does at noon on the 21st of March. If the

handle be turned round, when the solar ray comes to the western edge of the horizon, the hour index will point VI, which shews the time of sun-setting ; London then passes into, and continues in darkness, till the hour index having passed over XII hours, comes again to VI, at which time the solar ray gains the eastern edge of the horizon, thereby defining the time of sun-rising ; six hours afterwards the meridian again comes to the solar ray, and the hour index points to XII, thereby evidently demonstrating the equality of the day and night, when the sun is in the equinoctial ; you may then also observe, that the sun rises due east, and sets due west.

Continuing to move the handle, you will find that the solar ray declines from the equator towards the north, and every day at noon rises higher upon the graduations of the meridian than it did before, continually approaching to London, the days at the same time growing longer and longer, and the sun rising and setting more and more towards the north, till the 21st of June, when the earth gets into the first degree of Capricorn, and the sun appears in the tropic of Cancer, rising about 40 minutes past III in the morning, and setting about 20 minutes past VIII in the evening ; and after continuing about seven
hours

hours in the nether hemisphere, appears rising in the north-east as before. From the 21st of June to the 22^d of September, the sun recedes to the south, and the days gradually decrease to the autumnal equinox, when they again become equal.

During the three succeeding months, the sun continues to decline towards the south pole, till the 21st of December, when the sun enters the tropic of Capricorn, rising on the south-east point of the compass about 20 minutes past VIII in the morning, and setting about 40 minutes past III in the evening, at the south-west point upon the horizon; after which, the sun continues in the dark hemisphere for 17 hours, and then appears again in the south-east, as before. From the 21st of December the sun returns towards the north, and the days continually increase in length till the vernal equinox, when all things are restored in the same order as at the beginning.

Thus all the varieties of the seasons, the time of sun rising and setting, and at what point of the compass; as also the meridian altitude and declination every day of the year, and duration of twilight, and to what place the sun is at any time vertical,

vertical, are fully exemplified by this globe and it's apparatus.

Before we quit the phænomena particularly arising from the motion and position of the earth, let the globe, with the meridian and horizon, be removed, and the ivory ball which fits upon the pin be placed thereon, to represent the earth.

As the axis of this globe stands perpendicular to the plane of the ecliptic, you will find that the solar ray continually points at the equator of this little ball, and will never deviate to the north or south; though by turning the handle, the ball is made to complete a revolution round the sun. This shews that the earth in this position would have the days and nights equal in every part of the globe, all the year long; and that the variety of the seasons is owing to it's axis being inclined to the plane of it's orbit.

OF THE LUNARIUM, FIG. 2, PLATE XVIII.

Having thus illustrated the phænomena, which arise particularly from the inclination of the earth's axis to the plane of the ecliptic, from it's rotation round it's axis, and revolution round the sun;

sun ; we now proceed to explain, by this instrument, the phænomena of the moon ; but in order to this, it will be necessary to speak first of the instrument, which is put in motion like the preceding one, by the teeth on the fixed wheel ; it is also to be placed upon the same socket as the tellurian, and confined down by the same milled nut ; the sloping ring P Q represents the plane of the moon's orbit, or path, round the earth ; so that the moon in her revolution round the earth does not move parallel to the plane of the ecliptic, but on this inclined plane ; the two points of this plane, that are connected by the brass wire, are the nodes, one of which is marked Ω , for the ascending node, the other \Im for the descending node. As the moon is sometimes on the north, and sometimes on the south side of the ecliptic, which deviations from the ecliptic are called her north or south latitude ; her greatest deviation, which is when she is at her highest and lowest points, called her limits, is 5 deg. 18 min. ; this, with all the other intermediate degrees of latitude, are engraved on this ring, beginning at the nodes, and numbered both ways from them. At each side of the nodes we find, at about 18 degrees distance from them, a sun \odot , and at about 12 degrees a moon D , to indicate that when the full moon is got as far from the nodes as the mark D ,
there

there can then be no eclipse of the moon, nor any eclipse of the sun; when the new moon has passed the mark \odot , these points are generally termed the limits of eclipses.

The nodes of the moon do not remain fixed at the same point of the ecliptic, but have a motion contrary to the order of the signs. T V is a small circle parallel to the ecliptic; it is divided into 12 signs, and each sign into 30 degrees; this circle is moveable in it's socket, and is to be set by hand, so that the same sign may be opposite to the sun, that is marked out by the annual index. The moon's nodes are to be set to their place in this small ecliptic, which place is to be found by an ephemeris; R S is a circle, on which are divided the days of the moon's age; X Y is an ellipsis, to represent the moon's elliptical orbit, the direct motion of the apogee, or the line of the apsides, with the situation of the elliptical orbit of the moon, and place of the apogee in the ecliptic at all times.

Having rectified the lunarium for use, on putting it into motion it will be evident,

1. That

1. That the moon, by the mechanism of the instrument, always moves in an orbit inclined to that of the ecliptic, and consequently in an orbit analogous to that in which the moon moves in the heavens.
2. That she moves from west to east.
3. That the white or illuminated face of the moon is always turned towards the sun.
4. That the nodes have a revolution contrary to the order of the signs, that is, from Aries to Pisces; that this revolution is performed in about nineteen years, as in nature.
5. That the moon's rotation upon her axis is effected and completed in about $27\frac{1}{2}$ days; whereas it is $29\frac{1}{2}$ days from one conjunction with the sun to the next.
6. That every part of the moon is turned to the sun, in the space of her monthly or periodic revolution.

To be more particular. On turning the handle, you will observe another motion of the earth, which has not yet been spoken of, namely, it's

3 monthly

monthly motion about the common center of gravity, between the earth and moon, which center of gravity is represented by the pin Z. From hence we learn, that it is not the center of the earth which describes what is called the annual orbit, but the center of gravity between the earth and moon, and that the earth has an irregular, vermicular, or spiral motion about this center, so that it is every month at one time nearer to, at another further from the sun. It is evident from the instrument, that the moon does not regard the center of the earth, but the center of gravity as the center of her proper motion. That the center of the earth is furthest from the sun at new moon, and nearest at the full moon; that in the quadratures the monthly parallax of the earth is so sensible, as to require a particular equation in astronomical tables. These particulars were first applied to the orrery, by the late ingenious Mr. Benjamin Martin.

The phases of the moon are clearly exhibited in this instrument; for we here see that half which is opposite to the sun is always dark, while that which is next to the sun is white, to represent the illuminated part. Thus when it is new moon, you will see the whole white part next the sun, and the dark part turned towards the earth,
shewing

shewing thereby it's disappearance, or the time of it's conjunction and change: on turning the handle, a small portion of the white part will begin to be seen from the earth, which portion will increase towards the end of the 7th day, when you will perceive that half of the light, and half of the dark side, is turned towards the earth, thus illustrating the appearance of the moon at the first quarter. From hence the light side will continually shew itself more and more in a gibbous form, till at the end of fourteen days the whole white side will be turned towards the earth, and the dark side from it, the earth now standing in a line between the sun and moon; and thus the instrument explains the opposition, or full moon. On turning the handle again, some of the shaded part will begin to turn towards the earth, and the white side to turn away from it, decreasing in a gibbous form till the last quarter, when the moon will appear again as a crescent, which she preserves till she has attained another conjunction.

In this lunarium the moon has always the same face or side to the earth, as is evident from the spots delineated on the surface of the ivory ball, revolving about it's axis in the course of one revolution round the earth; in consequence
of

of which, the light and dark part of the moon appear permanent to us, and the phases are shewn as they appear in the heavens.

The tutor will be enabled by this instrument to explain some other circumstances to his pupil; namely, that as the earth turns round his axis once in 24 hours, it must in that time exhibit every part of it's surface to the inhabitants of the moon, and therefore it's luminous and opake parts will be seen by them in constant rotation. As that half of the earth which is opposed to the sun is always dark, the earth will exhibit the same phases to the lunarians that we do to them, only in a contrary order, that when the moon is new to us, we shall be full to them, and vice versa. But as one hemisphere only of the moon is ever turned towards us, it is only to those that are in this hemisphere who can see us; our earth will appear to them always in one place, or fixed in the same part of the heavens; the lunarians in the opposite hemisphere never see our earth, nor do we ever view the part of the moon that they inhabit. The moon's apparent diurnal motion in the heavens is produced by the daily revolution of our earth.

If we consider the moon with respect to the sun, the instrument shews plainly that one-half of her globe is always enlightened by the sun; that every part of the lunar ball is turned to the sun, in the space of her monthly or periodical revolution, and that therefore the length of the day and night in the moon is always the same, and equal to $14\frac{2}{3}$ of our day. When the sun sets to the lunarians in that hemisphere next the earth, the terrestrial moon rises to them, and they can therefore never have any dark night; while those in the other hemisphere can have no light by night, but what the stars afford.

The difference between the periodical month, in which the moon exactly describes the ecliptic, and the synodical, or time between any two new moons, is here rendered very evident. To shew this difference, observe at any new moon her place in the ecliptic, then turn the handle, and when the moon has got to the same point in the ecliptic, you will see that the dial shews $27\frac{1}{3}$ days, and the moon has finished her periodic revolution. But the earth at the same time having advanced in it's annual path about 27 degrees of the ecliptic, the moon will not have got round in a direct line with the sun, but will require 28 days and 4

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hours

hours more, to bring it into conjunction with the sun again.

There is nothing in astronomy more worthy of our contemplation, nor any thing more sublime in natural knowledge, than rightly to comprehend those sudden obscurations of the heavenly bodies, that are termed eclipses, and the accuracy with which they are now foretold. One of the chief advantages derived by the present generation, from the improvement and diffusion of philosophy, is delivery from unnecessary terror, and exemption from false alarms. The unusual appearances, whether regular or accidental, which once spread consternation over ages of ignorance, are now the recreations of inquisitive security. The sun is no more lamented when it is eclipsed, than when it sets; and meteors play their corruscations without prognostic or prediction.

We have already observed, that the sun is the only real luminary in the solar system, and that none of the other planets emit any light but what they have received from the sun; that the hemisphere which is turned towards the sun is illuminated by his rays, while the other side is involved
in

in darkness, and projects a shadow, which arises from the luminous body.

When the shadow of the earth falls upon the moon, it causes an eclipse of the moon; when the shadow of the moon falls upon the earth, it causes an eclipse of the sun.

An eclipse of the moon, therefore, never happens but when the earth's opaque body interposes between the sun and the moon, that is, at the full moon; and an eclipse of the sun never happens but when the moon comes in a line between the earth and the sun, that is, at the new moon.

From what we have already seen by the instrument, it appears that the moon is once every month in conjunction, and once in opposition; from hence it would appear, that there ought to be two eclipses, one of the sun, the other of the moon, every month; but this is not the case, and for two reasons, first, because the orbit of the moon is inclined in an angle of about 5 degrees to the plane of the ecliptic; and secondly, because the nodes of this orbit have a progressive motion, which causes them to change their place every lunation. Hence it often happens, that at the times of opposition or conjunction the moon

has so much latitude, or what is the same thing, is so much below or above the plane of the ecliptic, that the light of the sun will in the first case reach the moon, without any obstacle, and in the other the earth; but as the nodes are not fixed, but run successively through all the signs of the ecliptic, the moon is often, both at the times of conjunction and opposition, in or very near the plane of the ecliptic; in these cases an eclipse happens, either of the sun or moon, according to her situation. The whole of this is rendered clear by the lunarium, where the wire projecting from the earth, shews when the moon is above, below, or even with the earth, at the times of conjunction and opposition, and thus when there will be, or not, any eclipses.

The distance of the moon from the earth varies sensibly with respect to the sun; it does not move in a circular, but in an elliptic orbit* round us, the earth being at one of the foci of this curve. The longer axis of the lunar orbit is not always directed

* That point of her orbit wherein she is nearest the earth, is called her PERIGEE; the opposite point, in which she is farthest off, is called her APOGEE. These two points are called her APSIDES, the apogee is the higher, the perigee the lower apsis.

directed to the same point of the heavens, but has a movement of it's own, which is not to be confounded with that of the nodes ; for, the motion of the last is contrary to the order of signs, but that of the line of apfides is in the same direction, and returns to the same point in the heavens in about nine years. This motion is illustrated in the lunarium by means of the brass ellipsis X Y, which is carried round the earth in little less than nine years : thus shewing the situation of the elliptical orbit of the moon, and the place of the apogee in the ecliptic.

Those who wish to extend the application of the instrument further, may have an apparatus applied to it for explaining the Jovian and Saturnian systems, illustrating the motion of their satellites, and of the ring of Saturn. But as this application would extend the price of the instrument beyond the reach of most purchasers, I have thought it would be unnecessary to describe them ; the more so, as the phænomena they are intended to explain are accurately and clearly described in several introductory works of astronomy.

OF THE PLANETARIUM, TELLURIAN, AND
LUNARIUM, REPRESENTED IN PLATE XIX.

It is unnecessary to enter into a minute description of this instrument, as what has been said upon the last will apply to this, the difference being but small, and that calculated to render the instrument less expensive.

It differs from that delineated in plates XVII. and XVIII. in the following particulars :

1. That the parts do not take off, as in the other, for exhibiting the particular phænomena ; but the whole is put in motion at the same time.
2. That the part, which answers the purpose of the tellurian, is upon a much smaller scale than that of plate XVIII.
3. The lunarium only exhibits the monthly motion of the moon round the earth, the inclination of the nodes, and the phases.

To lessen the price still more, some of these instruments are constructed with no diurnal motion to the earth.

OF THE ARMILLARY SPHERE,
FIG. I, PLATE XIII.

This instrument represents a planetarium, as combined, or rather as inserted within an armillary sphere. The planetarium exhibits the motion of the earth, and all the primary planets, round the sun; the parallelism of the earth's axis, and the moon's motion round the earth, the seasons, &c. may therefore be explained by it; the propriety of placing them in a sphere, is too obvious to need explanation; the description of the foregoing instrument will enable the tutor to use this with ease to himself, and satisfaction to his pupil.

DESCRIPTION AND USE OF THE ARMILLARY
SPHERE, FIG. I, PLATE XIII.

Whoever has seen a common armillary sphere, and understands how to use it, must be sensible that the machine here referred to, is of a very different, and much more advantageous construction. And whoever has seen the curious glass sphere, invented by Dr. Long, or the figure of it in his astronomy, must know that the furniture of the terrestrial globe in this machine, the manner of turning either the earthly globe, or the circles which

surround it, are all copied from the doctor's glass sphere; and that the only difference is, a parcel of rings instead of a glass celestial globe; and all the additions are, a moon within the sphere, and a semicircle upon the pedestal.*

The exterior parts of this machine are a compages of brass rings, which represent the principal circles of the heaven, viz. 1. The equinoctial, which is divided into 360 degrees, (beginning at it's intersection with the ecliptic in Aries) for shewing the sun's right ascension in degrees; and also into 24 hours, for shewing his right ascension in time. 2. The ecliptic B B, which is divided into 12 signs, and each sign into 30 degrees, and also into the months and days of the year, in such a manner, that the degree or point of the ecliptic in which the sun is, on any given day, stands over that day in the circle of months. 3. The tropic of Cancer C C. 4. The arctic circle E, and the antarctic circle F, each $23\frac{1}{2}$ degrees from it's respective pole at N and S. 5. The equinoctial colure G G passing through the north and south poles of the heaven at N and S, and through the equinoctial points Aries and Libra, in the ecliptic. 6. The solstitial colure H H passing through the poles of the heaven, and

* Ferguson's Lectures, p. 194.

and through the solstitial points Cancer and Capricorn, in the ecliptic. Each quarter of the former of these colures is divided into 90 degrees, from the equinoctial to the poles of the world, for shewing the declination of the sun, moon, and stars; and each quarter of the latter, from the ecliptic to it's poles, for shewing the latitudes of the stars.

In the north pole of the ecliptic is a nut *b*, to which is fixed one end of a quadrantal wire, and to the other end a small sun *Y*, which is carried round the ecliptic *B B*, by turning the nut; and in the south pole of the ecliptic is a pin at *d*, on which is another quadrantal wire, with a small moon *Z* upon it, which may be moved round by hand; but there is a particular contrivance for causing the moon to move in an orbit which crosses the ecliptic at an angle of $5\frac{1}{3}$ degrees, in two opposite points, called the moon's nodes; and also for shifting these points backward in the ecliptic, as the moon's nodes shift in the heaven.

Within these circular rings is a small terrestrial globe *I*, fixed on an axis *KK*, which extends from the north and south poles of the globe, to those of the celestial sphere at *N* and *S*: on this axis is fixed the flat celestial meridian *L*, which

may be set directly over the meridian of any place on the globe, and then turned round with the globe, so as to keep over the same meridian upon it: this flat meridian is graduated the same way as the brass meridian of a common globe, and it's use is much the same. To this globe is fitted the moveable horizon M M, so as to turn upon two strong wires proceeding from it's east and west points to the globe, and entering the globe at opposite points of it's equator, which is a moveable brass ring let into the globe in a groove all around it's equator: the globe may be turned by hand within this ring, so as to place any given meridian upon it, directly under the celestial meridian L. The horizon is divided into 360 degrees all around it's outermost edge, within which are the points of the compass, for shewing the amplitude of the sun and moon, both in degrees and points. The celestial meridian L L passes through two notches in the north and south points of the horizon, as in a common globe; but here, if the globe be turned round, the horizon and meridian turn with it. At the south pole of the sphere is a circle of 24 hours, fixed to the rings, and on the axis is an index which goes round that circle, if the globe be turned round it's axis.

The whole fabric is supported on three feet, and may be elevated or depressed upon the joint O, to any number of degrees from o to q o, by means of the arc P, which is fixed into the strong brass arm Q, and slides in the upright piece R, in which is a screw at r, to fix it at any proper elevation. In the box T are two wheels (as in Dr. Long's sphere) and two pinions, whose axes come out at a and b; either of which may be turned by the milled nuts affixed to them. When the nut b is turned, the terrestrial globe, with it's horizon and celestial meridian, keep at rest; and the whole sphere of circles turns round from east, by south, to west, carrying the sun Y, and moon Z, round the same way, and causing them to rise above and set below the horizon; but when the nut a is turned forward, the sphere, with the sun and moon, keep at rest; and the earth, with it's horizon and meridian, turn round from west, by south, to east; and bring the same points of the horizon to the sun and moon, to which these bodies came when the earth kept at rest, and they were carried round it, shewing that they rise and set in the same points of the horizon, and at the same times in the hour circle, whether the motion be in the earth, or in the heaven. If the earthly globe be turned, the hour index goes round it's hour circle;

cle ; but if the sphere be turned, the hour circle goes round below the index.

And so, by this construction, the machine is equally fitted, to shew either the real motion of the earth, or the apparent motion of the heaven.

To rectify the sphere for use, first slacken the screw *r* in the upright stem *R*, and taking hold of the arm *Q*, move it up or down until the given degree of latitude for any place be at the side of the stem *R*, and then the axis of the sphere will be properly elevated, so as to stand parallel to the axis of the world, if the machine be set north and south by a small compass : this done, count the latitude from the north pole, upon the celestial meridian *L*, down towards the north notch of the horizon, and set the horizon to that latitude ; then turn the nut *b*, until the sun *Y* comes to the given day of the year in the ecliptic, and the sun will be at it's proper place for that day : find the place of the moon's ascending node, and also the place of the moon, by an ephemeris, and set them right accordingly. Lastly, turn the nut *b* until either the sun comes to the meridian *L*, or until the meridian comes to the sun, (according as you want the sphere or earth to move)

move) and set the hour index to the XII marked noon, and the whole machine will be rectified.

Then turn the nut a, and observe when the sun or moon rise and set in the horizon, and the hour index will shew the times thereof for the given day.

Those who understand the use of the globes, will be at no loss to work many other problems by this sphere.



ESSAY IV.

E S S A Y IV.

AN INTRODUCTION TO

PRACTICAL ASTRONOMY.

THERE is no part of mathematical science more truly calculated to interest and surprise mankind, than the measurement of the relative positions and distances of inaccessible objects. To determine the distance of a ship, seen on a remote spot of the unvaried face of the ocean ; to ascertain the height of the clouds and meteors which float in the invisible fluid above our heads ; or to shew with certainty the wonderful dimensions of the sun and other bodies in the heavens, are among the numerous problems

Q q

which

which to the vulgar appear far beyond the reach of human art, but are nevertheless truly resolved by the incontrovertible principles of the mathematics. These principles, simple in themselves, and easy to be understood, are applied to the construction of a variety of instruments; and the following pages contain an account of their use in the quadrant and the equatorial.

The position of any object, with regard to a spectator, can be considered in no more than two ways; namely, as to it's distance, or the length of a line supposed to be drawn from the eye to the object; and as to it's direction, or the situation of that line with respect to any other lines of direction: or in other words, whether it lies to the right or left, above or below those lines. The first of these two modes bears relation to a line absolutely considered, and the second to an angle. It is evident that the distance can be directly come at by no other means than by measuring it, or successively applying some known measure along the line in question; and therefore, that in many cases the distance cannot be directly found; but the position of the line, or the angle it forms, with some other assumed line, may be readily ascertained, provided this last line do likewise terminate in the eye of the spectator. Now the

whole artifice of measuring inaccessible distances, consists in finding their lengths, from the consideration of angles, observed about some other line, whose length can be submitted to actual mensuration. How this is done I shall proceed to shew.

Every one knows the form of a common pair of compasses. If the legs of this instrument were mathematical lines, they would form an angle greater or less, in proportion to the space the points would have passed through in their opening. Suppose an arc of a circle to be placed in such a manner, as to be passed over by these points, then the angles will be in proportion to the parts of the arc passed over; and if the whole circle be divided into any number of equal parts, as for example, 360, the number of these comprehended between the points of the compasses, will denote the magnitude of the angle. This is sufficiently clear; but there is another circumstance which beginners are not often sufficiently aware of, and which therefore requires to be well attended to: it is, that the angle will be neither enlarged nor diminished by any change in the length of the legs, provided their position remains unaltered; because it is the inclination of the legs, and not their distance from each, or the

space between them, which constitutes the angle. So that if a pair of compasses, with very long legs, were opened to the same angle as another smaller pair, the intervals between their respective points would be very different; but the number of degrees on the circles, supposed to be applied to each, would be equal, because the degrees themselves on the smaller circle would be exactly proportioned to the shortness of the legs. This property renders the admeasurement of angles very easy; because the diameter of the measuring circle may be varied at pleasure, as convenience requires. In practice, however, the magnitude of instruments is limited on each side. If they be made very large, they are difficult to manage, and their weight bearing a high proportion to their strength, renders them liable to change their figure, by bending when their position is altered; but on the contrary, if they are very small, the errors of construction and graduation amount to more considerable parts of the divisions on the limbs of the instrument.

OF THE QUADRANT AND IT'S USES.

Every circle being supposed to be divided into 360 equal parts, or degrees, it is evident that 90 degrees, or one-fourth part of a circle, will be
sufficient

sufficient to measure all angles formed between a fine perpendicular to the horizon, and other lines which are not directed to points below the level. Fig. 1, pl. XX. is a drawing of a very simple and useful instrument of this kind. A B C is a quadrant mounted on an axis and pedestal: by means of the axis, it may be immediately placed in any vertical position, and the pedestal being moveable in the axis of the circle E F, serves to place it in the direction of any azimuth, or towards any point of the compass. The limb A B is divided into degrees and halves, numbered from A; and upon the radius B C are fixed two sights, of which B is perforated with a small hole, and is provided with a dark glass, to defend the eye from the sun's light; and the other sight C has a larger hole, furnished with cross wires, and also a smaller, which is of use to take the sun's altitude by the projection of the bright image of that luminary upon the opposite sight. From the center C hangs a plumb line C P. The horizontal circle F E is divided into four quadrants of 90 degrees; and an arm E, connected with the pedestal, moves along the limb, and consequently shews the position of the place of the quadrant, as will hereafter be more minutely explained. Lastly, the screws G, H, I, render it very easy to set the whole instrument steadily and accurately in

it's proper position, notwithstanding any irregularity in the table or stand it may be placed upon.

The rationale of this instrument is very clear and obvious. It is used to measure the angular distance of any body, or appearance, either from the zenith or point immediately above our heads, or from the horizon or level. The plumb line CP , if continued upwards from C , would be directed to the zenith Z ; and the line CL , supposed to be drawn from the center of the quadrant to an object L , will form an angle LCZ , which is the zenith distance, and is equal to the angle BCP , formed between the opposite parts of the same lines. We see, therefore, that the degrees on the arc, comprehended on the limb of the quadrant, between the plumb line and the extremities next the eye, measure the angle of zenith distance.

Again, the line CK (forming a right angle with the perpendicular CZ) is level, or horizontal; the angle LCK must therefore be the altitude or elevation of L above the horizon: and this last angle must be equal to the angle measured between the plumb line and the end A farthest from the eye; because both these are equal

equal to the quantity which would be left, after taking the zenith distance from a right angle, or the whole quadrant.

The determination of the altitude or zenith distance of an object is not sufficient to ascertain it's place, because the object may be placed in any direction with respect to azimuth, or the points of the compass, without increase or diminution of it's altitude. Hence it is that an horizontal graduated circle is a necessary addition to a quadrant which is not intended to be always used in the same plane. The bearing or position of an object relative to the cardinal points, together with the altitude, is sufficient to ascertain the place of any object or phænomenon.

After this short account of the general principles of the quadrant, I shall proceed to shew some of the leading problems resolved by it.

PROBLEM I.

To adjust the quadrant for observation.

The quadrant is adjusted for observation when it's plane continues perpendicular to the horizon, in all positions of the line of sight. For this pur-

pose, bring the index to 90° on the horizon, and turn one or both of the screws which are fixed opposite 60° , till the plumb line lightly touches the plane of the quadrant. Then turn the index to 0° , and make the same adjustment, by means of the screw at 0° , and the quadrant is ready for observation.

Or otherwise, set the index at 0° , and observe the degree marked by the plumb line on the limb; then turn the index to the other 0° which is diametrically opposite, and observe the degree marked by the plumb line: if it be the same as before, there will be no occasion to alter the screws at 60° ; but if otherwise, one or both of those screws must be turned, till the plumb line intersects the middle degree (or part) between the two. After this operation, the degree marked by the plumb line must be observed, as before, by setting the index at both the 90° , and the adjustment of the plumb line to the middle distance must be made by the screw at O, taking care not to touch the other screws.

The latter method of adjustment being more accurate in practice, may be used after the former.*

P R O B L E M I I.

To find the distance of an object on the earth, by observations made from two stations on the same level.

O B S E R V A T I O N S.

Chuse two stations, between which the ground is level, and place a visible mark on each. The distance between them ought not to be less than the seventh or eighth part of the estimated distance of the object; and neither station ought to be considerably nearer the object than the other. Measure the distance between the stations, by means of measuring poles, a chain, or a piece of stretched cork. From one station direct

* The larger or more expensive instruments have apparatus for setting the axes of motion at right angles to the planes of the horizontal circle and quadrant, the line of sight or collimation parallel to the radius passing through 90° , &c. &c. In the small instruments, described in the text, these adjustments are made by the workman.

direct the quadrant to the object, by looking through the hole in one sight, and moving the upright axis about, till the object is seen through the hole in the other, exactly at the intersection of the cross wires. Observe the degrees and parts shewn by the index on the horizontal circle; then direct the quadrant in the same manner to the mark of the other station, and observe the degrees and parts shewn by the index. The number of degrees and parts intercepted between this and the former position of the index, is the angle at the first station. The same operations repeated at the second station, will give the angle at that station.

SOLUTION.

Take the sum of the two observed angles from 90° , and the remainder will be the angle under which the two station-marks would be seen from the object. Then

As the sine of the angle at the object
 Is to the sine of the angle at one station;
 So is the distance between the stations
 To the distance of the object from the other station,

These,

These, and all other proportions, may be solved by the logarithms, or more speedily by the Gunter's rule.

SOLUTION OF THE PROBLEM BY PROTRACTION.

From a scale of equal parts lay down a right line, to represent the measured base.

By means of the protractor, or by the compasses and line of chords, draw a line from each extremity of the base, respectively forming angles equal to those actually observed.

Continue these lines till they intersect.

The interval between the point of intersection, and one extremity of the base, being taken between the compasses, and applied to the line of equal parts, will shew the distance between the object and the station represented by that extremity.

This problem may, in cases of small distance, be conveniently applied to a base line measured within a room, and the observations taken out at the windows.

P R O B L E M I I I .

To find the distance of the foot of a tower, by observations made on the upper part.

The solution of this problem consists in making observations on the summit, in the same manner as in the foregoing problem. The distance deduced from the horizontal angles will be that of a point in the horizon, immediately beneath the part on which the observations were made.

P R O B L E M I V .

To find the height of a spire, a mountain, or any other elevation.

Case I. When the distance of the point immediately beneath the summit can be measured.

Observe the angle of altitude with the quadrant, by viewing the summit through the sights, and noting the degrees and parts indicated by the intersection of the plumb line. Measure also the horizontal distance.

Then,

Then,

As the co-sine of the observed angle
Is to the sine of the observed angle ;
So is the measured distance
To the height required.

Or by construction. Draw a right line equal to the measured base, taken from a scale of equal parts.

Erect a perpendicular from one extremity, and from the other draw a line inclined towards the perpendicular, and forming an angle with the base, equal to the observed angle.

The interval between the intersection of this last line, and the perpendicular, and the lower extremity of the perpendicular itself, being taken in the compasses, and applied to the line of equal parts, will shew the height required.

Case 2. When the distance of the point immediately beneath the summit cannot be measured.

Find

Find the distance by prob. iii. and the height by case 1, of the present problem: or otherwise,

Measure a base line directly towards the object, and take the altitude from each end of the base.

Then,

As the sines of the difference between the sum of
the two altitudes, and 180° ,
Are to the sine of the less altitude;
So is the base line
To the direct distance between the summit and
the nearer end of the base line.

And,

As radius
Is to the sine of the greater altitude;
So is the distance last found
To the height required.

Or by construction. Set off the base line, and from it's extremities draw lines inclined to the base in the respective angles observed, but in such a manner, as that the less angle may be formed by
the

the base itself, and the greater by the prolongation of the base.

These lines will intersect.

From the point of intersection let fall a perpendicular on the prolongation of the base, and it will give the height required.

The first method of solving this case is in general the best in practice. It is for the most part much more easy to find a base sufficiently long and level between two stations, nearly equi-distant from the eminence, as the first requires, than in a direction towards it, because the ground usually rises irregularly towards mountains. And in the latter case also, if the difference between the two altitudes be not very considerable, the result will be rendered erroneous by a very small inaccuracy of observation.

PROBLEM V.

To plot a field by a base line measured in the middle.

Set

Set up marks in the corners or angles, and measure a line in the field in such a direction, as that it may be as far as possible from pointing towards any of the angles. Direct the sights from one end of the base to each of the angles successively, and also to the other extremity of the base, carefully noting the degrees and parts of the horizontal circle, indicated by the index. Repeat the like operations at the other end of the base line.

Construction. Draw a faint line upon paper, upon which set off, from a scale of equal parts, the measured base. From it's extremities draw lines, forming the respective angles observed. The intersections of those lines will shew the corners, or angles, of the field, and must be joined by right lines.

This problem being nothing more than a determination of the position of the angular points with respect to the base line, by prob. 1, will be more accurate in practice, the more nearly the conditions there expressed are adhered to. If a base line cannot be had in view of all the angles, and in a convenient position, two or more base lines may be measured, and connected together
by

by the observation of the requisite angles ; or the three sides of a triangle may be measured in the field, according to the discretion of the ingenious learner, and the bearings of the corners of the field taken from such extremities of any of these measured lines, as are best adapted to the purpose.*

As this method is very far from being laborious, the practitioner will do well to measure the field twice, from a different base each time.

P R O B L E M

* It may be proper to observe, for the use of such as are unacquainted with surveying of land, that the English acre is 4840 square yards, and that land is most conveniently measured by the Gunter's chain of 22 yards in length, divided into 100 links; because the square chain, or 22 multiplied by 22, equal to 484, is exactly the tenth part of an acre. If the plot of a field measured in chains and links, be therefore made upon paper, and divided into a number of triangles, by drawing right lines within it, the base and perpendicular of each triangle may be measured from the scale of equal parts, and half their product will be the area of the triangle in square chains ; the sum of all the areas of the triangles will be the area of the field, which divided by 10, will shew the number of acres ; the remaining decimal fraction multiplied by 4, gives the roods ; and the decimal part of this last product multiplied by 40, gives the perches,

P R O B L E M VI.

To plot a field, by measuring the sides and angles.

Set up marks at each of the angles, and at every one of these marks direct the quadrant to the two adjacent marks on each side. The number of degrees and parts between the two positions of the index on the horizontal circle, will shew the angle at the station where the observation is made. Measure the distance to the next station, and observe the angle there in the same manner. And thus proceed completely round the field.

Construction. From the scale of equal parts draw a line equal to the first measured side, and from it's extremities draw two lines, forming angles equal to those actually observed.

Make these last lines equal to the sides they represent, and from their extremities draw two other lines at angles respectively found by observation.

Proceed thus, till the whole field is plotted.

When

When all the angles of a field are thus measured, their sum, if the operation has been truly made, will be equal to twice as many right angles, deducting four, as there are angles in all, provided they be all inward angles. But if any of them be outward angles, their respective supplements to 360° must be taken in making up the sum, instead of the angles themselves. When the sum proves either greater or less than just the figure, it will not answer on paper; and as observations made with small instruments cannot be expected to be free from perceptible errors, it will be expedient to correct the angles by adding or subtracting such defect or excess, to or from all the angles, in proportion to their magnitude, or more readily in equal proportions among them.

This way of measuring is much used in America, by the measuring wheel and mariner's compass, and is applicable to extensive woody or mountainous tracts of land, where great accuracy is not required. It may also be used in conjunction with other methods, for delineating a sea-coast, &c.

P R O B L E M VII.

To find the altitude and height of fire balls, and other meteors, in the atmosphere.

Though the extreme velocity and tranſient nature of fiery meteors in the atmosphere in a great measure prevents the making of ſuch obſervations as might tend to aſcertain their diſtance, yet they form a ſubject of inquiry ſo curious and intereſting, as renders ſuch as can be made of great value. An obſerver, who perceives an appearance of this kind, ought carefully to note the buildings, trees, ſtars, &c. near which it paſſes; and as ſoon afterwards as convenient take their altitude and bearings. If two ſuch obſervations be taken by perſons at different places, ſufficiently diſtant from each other, the diſtance on the earth may be conſidered as the baſe, and from this and the two obſerved angles the height of the meteor may be found by problem ii.

By obſervations of this kind it has been found, that the larger fire balls are elevated about 60 miles above the earth's ſurface, and that ſome of them are near five miles in diameter.

P R O B L E M VIII.

To find the height of a cloud, by observation
of a flash of lightning.

If the altitude of that part of a cloud from which a flash of lightning has issued, be immediately taken with the quadrant, and the number of seconds of time elapsed between the instant of the flash, and the first arrival of the thunder be reckoned, these data will be sufficient to determine the height of the thunder cloud. For sound is admitted to pass through 1142 feet in a second; but light has such an extreme velocity, that it passes through thirty-five thousand miles in a second, and may therefore be reckoned instantaneous in all observations upon the earth. Hence it follows, that the number of seconds observed, multiplied by 1142, will give the distance of the cloud in feet; and

As radius

Is to the sine of the observed angle;

So is the distance of the cloud

To it's height.

Or by construction. From a point in any right line, draw another right line, forming the observed angle. Set off on this left line, from the angular point, the distance of the cloud, taken from a scale of equal parts. From the extreme of the last-mentioned line let fall a perpendicular on the other line ; and this perpendicular will be the height required.

If the flash of lightning strike directly down, the height of the cloud will also be the length of the flash. But this is not often the case.

PROBLEM IX.

To determine the height of a cloud, by observations on it's altitude and velocity.

When the sky abounds with detached clouds, moving with considerable velocity, it is easy to determine the degree of swiftness, by observing the progress of their shadows which pass along the ground. For this purpose, nothing more is necessary, than to note the instants of time when one of these shadows passes over two objects, such as hedges, trees, &c. lying in it's direction ; and to measure the interval passed over, during the intermediate time. When this velocity is thus

thus found, place the plane of the quadrant in the direction of the wind, and setting the sights to a considerable altitude, to be written down, take notice of some remarkable edge of a cloud, which passes across the wire in the aperture of the farthest sight, giving notice at the same instant to an assistant to note the time. Then move the quadrant on it's axis twenty or thirty degrees, and give the like notice to the assistant when the same part of the cloud passes the wire ; write down this last altitude. The perpendicular height of the cloud will be found by the following proportions.

As the number of seconds observed when the shadow of the former cloud was seen on the ground

Is to the number of seconds elapsed between the two observations with the quadrant ;

So is the distance measured on the ground

To the distance passed through by the cloud (whose altitude was taken) during the time of observation.

Then,

As the sine of the difference between the sum of
the two altitudes and 180°
Is to the sine of the less altitude ;
So is the distance passed over by the cloud
To it's distance from the observer, when the
greater altitude was taken.

And lastly,

As radius
Is to the sine of the greater altitude ;
So is the distance last found
To the perpendicular height of the cloud.

PROBLEM X.

To find the altitude of the sun, or any other
celestial body.

This consists in the simple application of the
quadrant to a celestial body, in the same manner
as has already been shewn with regard to terrestrial
objects. The quadrant being rectified or adjusted
by problem 1, as it must be in all cases previous
to it's use, the celestial body must be viewed
through the sights, and the plumb-line will shew
it's

it's altitude on the graduated limb of the instrument. If the observation be made on the sun, the dark glass must be used to defend the eye, or the luminous spot formed by the smaller hole of that sight which carries the cross wires, must be made to fall on the mark on the other sight which lies immediately beneath the eye-hole.

P R O B L E M X I .

To find the latitude of the place of observation.

When the sun, or a star, is nearly on the meridian, or a few minutes before twelve at noon, take it's altitude, and repeat this operation at short intervals of time, till it is found not to increase, but diminish. This last or greatest altitude is the meridian altitude.

In places where the sun does not set, the least altitude is the meridian altitude beneath the pole.

The rule for finding the latitude by the meridian altitude of an object not beneath the pole, is as follows :

If the co-altitude and declination* be of the same name, (that is, either both north, or both south) their difference will be the latitude; if of different names, their sum will be the latitude. And the latitude will always be of the same name with the declination, excepting when the declination has been subtracted from the co-latitude.

But when the altitude is beneath the pole, the following is the rule:

Add the altitude and the co-declination together, and the sum will be the latitude of the same name with the declination.

PROBLEM XII.

To find the time by equal altitudes of the sun.

Observe the sun's altitude in the morning, and also the time by a clock or watch. Leave the quadrant in the same situation, taking care that it's position be not altered by any accident; and in the afternoon direct it to the sun, by moving the index of the horizontal circle only. Add the
time

* The declination of the sun, and most other moveable celestial bodies, is to be found in the ephemerides.

time when the sun's altitude corresponds with that to which the quadrant was set in the morning. The middle instant between the two times of observation, is the time of apparent noon. Correct this, by adding or subtracting the equation of time, and it will shew the time of true noon. If it be precisely XII, the clock is right; but if it differ, the clock is faster or slower, by the quantity of the difference greater or less than XII.

P R O B L E M XIII.

To draw a meridian line, or to find the cardinal points of the compass, by equal altitudes of the sun, or a star.

If equal altitudes of the sun be taken as directed in the foregoing problem, and the place of the index on the horizon circle be carefully noted at each time of observation, the middle degree or part between each will be the place where the index will stand when the sights of the quadrant are directed to the south, or north, according as the sun is to the southward or northward of the place of observation at noon. Set the index to this middle point, and direct the
sights

sights of the quadrant to some remote and fixed object on the earth. This object will be a south meridian mark, and will serve to set the quadrant at any future time. Then take up the instrument, and after setting the index to 0, place it again on the table, or support, and move the whole instrument, not by any of it's parts, but entirely about upon the table, till the sights are truly directed to the meridian mark. Adjust the horizontal circle by prob. 1, and the index will then serve to shew the true bearing of any object; because the diameter joining the two zeros, or 00's, answers to the meridian line.

If the table, or support, be immoveable, it will be proper to make three marks, or indentations, to receive the points of the screws; by which means the horizontal circle may be instantly, at any time, set in it's proper position, with respect to the cardinal points of the horizon.

Observations of equal altitude are, generally speaking, better, the greater the interval is between them, not exceeding 12 hours; and these observations on the sun require some correction, on account of the change of it's declination during the time of observation. The young astronomer with small instruments may, however,
neglect

neglect this; and indeed it is of little consequence about the solstices, when the sun's declination changes very slowly.

It often happens that there is not any window in a house, from which the sun can be seen morning and evening. In this case, the meridian may be determined by observations of equal altitude of the pole star, or any other near the pole.

P R O B L E M X I V .

To find the time by the sun's transit over the meridian.

Adjust the quadrant to the cardinal points by the last problem, a short time before noon. Set the index to 0, and elevate the quadrant, so that the shadow of the sight with the cross wires may fall upon the other. As the instant of apparent noon approaches, the bright spot formed by the sun's light through the lower hole in the former sight, will be seen approaching the mark on the latter. If the observer chuses to look at the sun, he must now put up the dark glass, and apply to the observations. The instants when the first limb or edge of the sun appears to touch the perpendicular wire, and also when the latter limb appears

appears to leave it, must be noted by the clock or watch. The middle time is the apparent noon. Or if he chuses to observe by the bright spot only, the instant when the spot is seen upon the mark is the apparent noon. And this corrected by the equation of time, as directed in prob. xii. will shew how much the clock is fast or slow.

P R O B L E M XV.

To find the time by an observation of the sun's altitude and azimuth.

Adjust the instrument to the cardinal points, and observe the sun's altitude. Take notice likewise of the angle of azimuth from the meridian, as shewn by the index.

Then,

As the sine complement of the sun's declination
Is to the sine complement of the altitude ;
So is the sine of the azimuth
To the sine of the sun's horary angle.

Which last being reduced into time, by allowing fifteen degrees to one hour, and in proportion for the other parts, gives the apparent time,

if

if afternoon ; but if before noon, it must be deducted from 12 hours, to give the time. This apparent time must be corrected by the equation, as in problem xii.

OF THE EQUATORIAL, OR UNIVERSAL SUN-DIAL,
AND IT'S USES.

The plumb-line, or direction in which gravity acts, being the only line we can at all times have immediate recourse to, for determining the positions of objects, is the chief particular to which the circles in the instrument last described are adapted ; and accordingly, their planes are placed the one parallel, and the other perpendicular to that line. But as there are few places on the earth whose vertical or horizontal circles correspond with those in which the celestial motions are performed, it was found necessary, at a very early period, to construct instruments adapted not only to the measurement of altitudes and azimuths, but also to follow the heavenly bodies in their respective paths, and determine their right ascensions and declinations, more immediately than can be done by the quadrant and horizontal circle. The equatorial is the most approved modern instrument for this purpose.

It consists of the following parts :

An horizontal circle E F, plate XX. fig. 2, divided, like that of the former instrument, into four quadrants, of 90° each. But instead of a moveable index there is a fixed nonius plate at E, and the circle itself may be turned on it's axis.

In the center of the horizontal circle is fixed a strong upright pillar, which supports the center of a vertical semicircle A B, divided into two quadrants of 90° each. This is called the semicircle of altitude, and supplies the place of the quadrant in the former instrument, but it is more extensively useful, because one quadrant serves to measure altitudes, and the other depressions. It has no plumb-line, but a nonius plate at K.

At right angles to the plane of this semicircle, the equatorial circle M N is firmly fixed. It represents the equator, and is divided into twice twelve hours, every hour being divided into twelve parts, of five minutes each.

Upon the equatorial circle moves another circle, with a chamfered edge, carrying a nonius, by which the divisions on the equatorial may be

read

read off to single minutes ; and at right angles to this moveable circle is fixed the semicircle of declination D, divided into two quadrants of 90° each.

The piece which carries the sights O P is fixed to an index moveable on the semicircle of declination, and carrying a nonius at Q. The sight O, to which the eye is to be applied, has two small holes, and a dark glass for covering either occasionally ; and the sight P has two pieces screwed on, the lower having a small hole to admit the solar ray, and the upper carries two cross wires.

Lastly, there are two spirit levels fixed on the horizontal circle at right angles to each other.

The following are among the many problems which may be solved with peculiar facility, by means of this useful instrument.

P R O B L E M X V I .

To adjust the equatorial for observation.

Set the instrument on a firm support. First, to adjust the levels, and the horizontal or azimuth circle. Turn the horizontal circle, till the
S s
beginning

beginning O of the divisions coincides with the middle stroke of the nonius, or near it. In this situation, one of the levels will be found to lie either in a right line joining the two feet screws which are nearest the nonius, or else parallel to such a right line. By means of the two last-mentioned screws, cause the bubble in the level to become stationary in the middle of the glass; then turn the horizontal circle half round, by bringing the other O to the nonius; and if the bubble remains in the middle, as before, the level is well adjusted; if it does not, correct the position of the level, by turning one or both of the screws which pass through it's ends, (by means of a turn-screw) till the bubble has moved half the distance it ought to come to reach the middle; and cause it to move the other half, by turning the foot-screws already mentioned. Return the horizontal circle to it's first position, and if the adjustments have been well made, the bubble will remain in the middle; if otherwise, the process of altering the level and the foot-screws, with the reversing, must be repeated till it bears this proof of it's accuracy. Then turn the horizontal circle till 90° stands opposite to the nonius; and by the foot-screw, immediately opposite the other 90° , (without touching the others)

others) cause the bubble of the same level to stand in the middle of the glass. Lastly, by it's own proper screws set the other level (not yet attended to) so that it's bubble may occupy the middle of it's glass.

Secondly, to adjust the line of sight. Set the nonius on the declination semicircle at O; the nonius on the horary circle at VI; and the nonius on the semicircle of altitude at 90° . Look through the sights towards some part of the horizon, where there is a diversity of remote objects. Level the horizontal circle, and then observe what object appears on the center of the cross wires. Reverse the semicircle of altitude, so that the other 90° may apply to the nonius; taking care, at the same time, that the other three noniuses continue at the same parts of their respective graduations as before. If the remote object continues to be seen on the center of the cross wires, the line of sight is truly adjusted; but if not, unscrew the two screws which carry the frame of the cross wires, and move the frame till the intersection appears to lie on a new object, half way between the object first observed, and that to which the wires are applied in the last position. Return the semicircle of altitude to it's original position: if the intersection of the wires

be then found to be on the object to which they were last directed, the line of sight is truly adjusted; but if not, the frame must be again altered as before: and the same general operation must be repeated, till the cross wires in both positions apply to the same object.

Besides this adjustment of the center of intersection, it is necessary that one of the wires should be in the plane of the declination semicircle, and the other at right angles to that plane. As the wires are fixed at right angles to each other, the adjustment of one of them will be sufficient. For this purpose, observe any small object on one of the wires: if it be the vertical wire, move the index of the semicircle of declination; or if the other, move the last-mentioned semicircle on the axis of the equatorial circle. In either case the object will coincide with the wire during its motion, if the position be right; if not, alter that position, taking care not to displace the center from its adjustment.

To adjust the piece which carries the hole for forming the solar spot, direct the sights to the sun, so that the center of the luminous circle formed by the aperture which carries the cross wires, may fall precisely on the upper sight hole.

Then

Then move the frame, with the small perforation, till the solar spot falls exactly on the lower sight-hole.

Thirdly, to find the correction to be applied to observations by the semicircle of altitude. Set the nonius on the declination semicircle to O; and the nonius on the horary circle to XII. Direct the sights to any fixed and distinct object, by moving the horizontal circle and semicircle of altitude, and nothing else. Note the degree and minute of altitude or depression. Reverse the declination semicircle, by directing the nonius on the horary circle to the opposite XII. Direct the sights again to the same object, by means of the horizontal circle and semicircle of altitude, as before. If it's altitude, or depression, be the same as was observed in the other position, no correction will be required; but if otherwise, half the difference of the two angles is the correction to be added to all observations or rectifications made with that quadrant, or half of the semicircle, which shewed the least angle; or to be subtracted from all observations or rectifications made with the other quadrant, or half.

When the levels and cross wires are once truly set, they will preserve their adjustment a long

time, if not deranged by violence; and the correction to be applied to the semicircle of altitude, is a constant quantity.

P R O B L E M XVII.

To measure angles, either of azimuth, altitude, or depression.

Set the middle mark of the nonius on the declination at O, and fix it by means of the milled screw behind. Set the horary circle at XII on the equator, and the instrument (previously adjusted) is ready for observation. Then if the sights be directed successively to any two objects, the degrees and minutes contained between the two positions of the nonius, on the limb of the horizontal circle, will shew the horizontal angle in the same manner as has been described at prob. ii. of the quadrant. And likewise, if the sights be directed to any object, by moving the horizontal circle and semicircle of altitude, the degree and minute marked by the nonius on the last-mentioned semicircle will be the angle of altitude, if on the quadrant or part nearest the eye, or of depression, if on the remoter quadrant.

Remark.

Remark. It is proper in this place to describe the nature and use of the admirable contrivance commonly called a nonius. It depends on the simple circumstance, that if any line be divided into equal parts, the length of each part will be greater, the fewer the divisions; and contrariwise, it will be less in proportion as those divisions are more numerous. Thus it may be observed, that the distance between the two extreme strokes on the nonius, in the equatorial before us, is exactly equal to 11 degrees on the limb, but that it is divided into 12 equal parts. Each of these last parts will therefore be shorter than the degree in the proportion of 11 to 12; that is to say, it will be one-twelfth part, or 5 minutes shorter. Consequently, if the middle stroke be set precisely opposite to any degree, the relative positions of the nonius and the limb must be altered 5 minutes of a degree, before either of the two adjacent strokes next the middle, on the nonius, can be brought to coincide with the nearest stroke of a degree; and so likewise, the second strokes on the nonius will require a change of 10 minutes; the third, of fifteen, and so forth to thirty, when the middle line of the nonius will be seen to be equi-distant between two of the strokes on the limb; after which, the lines on the opposite side

of the nonius will coincide in succession with the strokes on the limb.

It is clear from this, that whenever the middle stroke of the nonius does not stand precisely opposite to any degree, the odd minutes, or distance between it and the degree immediately preceding, may be known by the number of the stroke on the nonius, which coincides with any of the strokes on the limb. It must be observed, however, that as the degrees in the several quadrants are reckoned in opposite directions, so likewise the nonius has two sets of numbers; for the use of which, it need only be remembered, that they always begin from the middle, and go to 30 minutes, and thence from the opposite 30 minutes in the same direction, to the middle; and that they must always be reckoned in the opposite direction to the degrees on the limb.*

PROBLEM

* In this instrument they must be read in the opposite direction; but when the nonius plate has its divisions fewer than the number of parts on the limb to which it is equal, they coincide successively in the same direction as that of the motion of the index.

P R O B L E M X V I I I .

To find the distance of an object on the earth, by observations made at two stations.

This may be done by measuring a base line and the horizontal angles, and proceeding as directed at problem ii. But as the equatorial measures angles of depression, as well as elevation, the stations may not only be on the same level, but may be vertically the one above the other. For example, if the altitude of any object be taken from a lower window of any building, and it's depression from a window immediately above, and the distance of the two stations of the instrument be accurately measured,

Then,

As the sine of the sum of the angles of altitude and depression (or of the difference, if both be altitude, or both depression)

Is to the sine of the angle at the upper station ;

So is the distance between the stations

To the distance of the object from the lower station.

P R O B L E M X I X .

To measure heights and distances.

As the semicircle of altitude answers every purpose of the quadrant, in the instrument before described, and the horizontal circle is common to both, it will be easy for the intelligent learner to perform the problems iii. iv. vii. viii. and ix. by the equatorial, from the instructions given under each respectively.

P R O B L E M X X .

To plot a piece of land.

The problems v. and vi. with all others which are solved by the mensuration of horizontal angles, may likewise be performed with great facility by the equatorial.

PROBLEMS XXI. XXII. XXIII. and XXIV.

Under this title it may be observed, that the problems xi. xii. xiii. xiv. and xv. for finding the latitude, the time by equal altitudes, the position of the cardinal points, and the time by the sun's transit over the meridian, or by it's altitude
and

and azimuth, may be performed with equal ease, and greater accuracy, by the horizontal circle and semicircle of altitude, in the instrument before us, as by the quadrant treated of under those problems.

I shall now proceed to some of the problems, to which the equatorial is more peculiarly adapted.

P R O B L E M XXV.

To find the latitude of a place, the sun's declination being known.

Place the adjusted equatorial, a short time before noon, in such a position, that the planes of the semicircles of altitude and declination may be as near the meridian as estimation will allow; and let the sight which carries the cross wires be turned to the point of the compass, (either north or south) to which the sun will come at noon. Set the index on the declination semicircle to the degree and minute of the sun's declination, either to the north or south side of O, as the case may be. Then by means of the horizontal circle and semicircle of altitude, without touching the declination semicircle, cause the solar spot to fall

4
on

on the mark in the opposite sight, (or observe the sun itself by the cross wires). Keep the sights in this manner directed to the sun, till his altitude begins to diminish. The degree and minute on the semicircle of altitude is the co-latitude, and the latitude will be north, if that degree and minute be upon the northermost quadrant; but if otherwise, south.

P R O B L E M XXVI.

To find the meridian line, and the time, from one observation of the sun, when it's declination and the latitude of the place are known.

This problem requires that both the azimuth and altitude of the sun should alter quickly; and this is, generally speaking, the case, more eminently, the farther that luminary is from the meridian. Therefore,

At the distance of several hours, either before or after noon, adjust the horizontal circle; set the semicircle of altitude, so that it's nonius may stand at the co-latitude; lay the plane of the last-mentioned semicircle in the meridian, by estimation, it's O being directed towards the depressed pole; place the nonius of the declination semicircle

circle to the declination, whether north or south. Then direct the line of sight towards the sun, partly by moving the declination semicircle on the axis of the equatorial circle, and partly by moving the horizontal circle on it's own axis. There is but one position of these which will admit of the solar spot falling directly on the mark on the opposite sight. When this position is obtained, the nonius on the equatorial, or horary circle, shews the apparent time, and the circle of altitude is in the plane of the meridian.

P R O B L E M XXVII.

To find the time, when the latitude, the sun's declination, and the meridian are known.

The meridian being found by equal altitudes of the sun, or a star, which is the best method, and settled by a meridian mark, or by indentations, to set the screws in, (prob. xiii.) place the equatorial accordingly, and adjust it by the levels. Set the semicircle of altitude to the latitude of the place, and the index of the line of sight, to the declination of the sun. Turn this last semicircle, till the sights are accurately directed to the sun. The nonius will shew the time on the horary circle.

This

This problem is more accurate than the foregoing, and may be applied at all times when the sun is visible.

P R O B L E M XXVIII.

To find the meridian line, when the time, the sun's declination, and the latitude of the place are known.

Adjust the instrument. Set the semicircle of altitude to the latitude, and the nonius of the declination semicircle to the declination; and set the nonius of the horary circle to the apparent time. Turn the horizontal circle till the sights are directed to the sun. The semicircle of altitude is then in the plane of the meridian.

This problem gives the position of the meridian more accurately than problem xxvi. It is much more ready where the time can be had, than the method of equal altitudes, and it is near enough to the truth for small instruments. The nearer the observation is made to the time of noon, the better, because the sun then changes its azimuth the quickest.

P R O B L E M XXIX.

To find the declination of the sun, or any celestial object, when the latitude of the place, and position of the meridian, are known.

Rectify the instrument for the latitude, as in the foregoing problem; and place the semicircle of altitude in the meridian. Then direct the sights to the object, partly by moving the declination semicircle on the axis of the equatorial circle, and partly by moving the nonius of the semicircle last-mentioned. This nonius will then shew the declination.

P R O B L E M XXX.

To find the right ascension of any celestial object, when the time, the latitude, and the position of the meridian, are known.

Perform the operations directed in prob. xxix. Place the sight so that the vertical wire may be a little to the westward of the object; and observe by a clock, or watch, the apparent or solar time when it crosses the wire. The shortest interval between the time of observation and the time marked on the equatorial circle, by the nonius, is

is the difference between the times of each luminary coming to the window.

If the stars precede the sun, this difference must be subtracted from, or if otherwise, added to the sun's right ascension; and the difference, or sum, will be the star's right ascension, provided it do not exceed 24 hours; if it do, the excess is the right ascension.

If the sun's right ascension should be too small to admit of taking the difference from it, it must itself be taken from the difference; and the supplement of the remainder to 24 hours, will be the star's right ascension.

P R O B L E M XXXI.

To direct the line of sight to any star or planet.

Adjust the instrument to the latitude and meridian, and set the nonius on the declination circle to the declination of the star. Then take the difference between the right ascension of the sun and star; and if the right ascension of the star be greater than that of the sun, subtract the difference; if not, add it to the time of observation.

The

The remainder, or sum, will be the hour and minute to which the nonius on the horary circle is to be set; which being done, the sights will point to the star or planet sought.

If the time be too small to admit of having the difference taken from it, borrow 24 hours, and reckon the remainder from XII at noon.

When the star or planet has, by the diurnal motion of the earth, been carried out of the field of view, in which the cross wires are placed, it may be readily overtaken, by moving the declination semicircle on the equatorial circle.

There are many other pleasant and useful problems, both terrestrial and astronomical, which may be solved by these instruments; but they cannot here be enlarged on, consistently with the intended limits of the present work. The intelligent student will discover some of them himself, and for the rest he may consult Atwood's *Analysis of a Course of Lectures*, De La Lande's *Astronomie*, and other approved authors. It will be seen, likewise, that I have not entered into the minute considerations of refractions, the variation of declinations, and other elements for parts of days, &c. neither have I described any

T t of

of the ingenious artifices, by which the errors of instruments are either corrected or allowed for. In this, also, I think the judicious teacher will join me in opinion, that though they are deservedly esteemed of the highest importance in the accurate operations of modern astronomy, yet it would not have been adviseable to have diverted the attention of the learner, before his curiosity was excited by a display of the leading particulars, even on the supposition that my plan could have allowed room for entering into such a detail.

The learner need not, however, be too diffident in attempting to discover them by his own reflections, after he has acquired a perfect knowledge of the contents of the foregoing pages. There is no doubt but he will then see with that pleasure which attends successful investigation, the excellence of the equatorial, and the numerous methods by which it's parts may be made to co-operate, in producing much more accurate results than it's size may seem to promise. In the mean time I shall conclude this article with a description of an improved equatorial, in which every endeavour has been used to unite simplicity of construction with delicacy and precision of workmanship.

DESCRIPTION OF THE IMPROVED EQUATORIAL.

The leading requisites in good astronomical instruments, are, 1. the parts must be firmly connected, so that they may always preserve the same figure; 2. the arcs must be truly centered, and accurately graduated; and 3. the extremity of the line of sight must in all simple motions describe a true circle. The two former either are or ought to be found in all instruments, whatever may be their form; but the latter property requires a particular construction. It is obvious, that when the line of sight, or telescope, is moved on the surface of one of the circles of an instrument, it's motion will be affected by every irregularity or deviation of that surface from a true plane; but on the contrary, if the motions be performed about axes well fitted, the extremity of the line of sight will in all situations remain directed to some point in the circle, in which it may be placed. The difficulty of obtaining and preserving the true surface in the former case, has induced all astronomers to give the preference to axes of motion, in such instruments as are intended to be used in observing transits of the celestial bodies, across the plane of the circle in which the line of sight is moved; and as a great part of the observations made with the equatorial,

are of the nature of those transits, it is a very desirable quality that all it's movements should be made upon axes, instead of their being governed by the planes of the circles it is composed of.

In the present instrument (plate XXI.) this circumstance is particularly attended to. EF is the horizontal circle firmly connected to another circular piece by fix vertical pillars. The distance between these two circles affords a convenient situation for a strong upright axis, on which the whole of the upper part of the instrument may be horizontally turned. The circular piece, which is screwed upon the head of the vertical axis, carries a spirit level. It also has an adjusting screw on one of it's edges, and a nonius plate on the other, which shews minutes. This piece supports the two uprights, upon which the axis of the semicircle of altitude AB turns. At right angles to the semicircle of altitude is fixed the equatorial or horary circle, from the center of which last proceeds a strong axis, that carries the apparatus for supporting the telescope. The horary motion of the telescope is performed by an adjusting screw, connected with an index that carries a nonius, for dividing the hours into portions of ten seconds each. The telescope has a strong but light axis, whose circular ends turn in
moveable

moveable sockets of hard metal, one of which is capable of a vertical, and the other of an horizontal adjustment. One end of the axis is perforated, and has a small convex lens set in the opening, through which, by the help of a reflector within, the cross wires may be illuminated for making observations on the stars at night. The semicircle of declination D is affixed to the telescope, and passes very near a nonius Q, which shews minutes on the limb. I shall now proceed to describe the method of adjustment and observation, which will render a more minute enumeration of the parts unnecessary, and will at the same time shew their use much better than can be done by mere description.

An attentive view of the instrument, or drawing, compared with what has been said before, at problem xvi. will shew that it's perfect adjustment consists in the following particulars.

1. The horizontal circle E F must be truly level.
2. The plane of the semicircle of altitude A B must be truly perpendicular to the horizon, or it's axis must be level.
3. The horary circle M N must be parallel to the horizontal circle E F, when the nonius of the semicircle of altitude marks 0 degrees; or at least the error of the position of the nonius must be found.
4. The

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axis

axis of the horary circle, or the polar axis, must be at right angles to the plane of that circle. 5. The line of sight, or optical axis of the telescope, must be at right angles to it's axis of motion. 6. The cross axis of the telescope must be parallel to the plane of the horary circle; and (7.) parallel to that of the semicircle of altitude, when the nonius marks the hour of VI. Lastly, the line of sight must be parallel to the horary circle, when the nonius of the semicircle of declination marks 0 degrees.

The manner of making these adjustments may be as follows. 1. Level the horizontal circle as described in problem xvi. 2. The plane of the semicircle of altitude is adjusted in the original construction of the instrument. 3. Set the horary index at XII, and direct the telescope to a remote object; set the index to the opposite XII, and turn the horizontal moveable circle half round. If the telescope then points to the same object, the horary circle is parallel to the horizon; if not, alter the position of the semicircle of altitude, till the telescope continues to point to one single object in both positions of the horary index. When this adjustment is made, take notice of the situation of the nonius of the semicircle of altitude; if it cuts at 0 degrees, it is rightly placed;

placed ; if not, note the difference, to be applied as a correction of all observations made with that semicircle. 4. The axis of the horary circle is truly placed in the construction. 5. Cause the vertical cross wire of the telescope to intersect a remote object, the adjusting screws of the horizontal and horary circles being previously made fast ; then reverse the position of the axis, so that the semicircle of declination may be upwards instead of downwards. By the motion on the axis it will be seen whether the same cross wire intersects the object seen in the former position ; if it do, the line of sight is at right angles to the axis of motion ; but if not, alter the position of the cross wires, by means of the two small screws near the eye end of the telescope, one of which must be unscrewed a little, and the other screwed up, till the desired proof, the accuracy of the position of the telescope, be attained. 6. Hook the arms of the hanging levels upon the ends of the axis of the telescope, having previously placed the horizontal and horary circles level. By means of the small capstan screw beneath one end of the axis, cause the bubble of the hanging level to occupy the middle of it's glass. Unhook the level, and hang it again on the axis, but in a contrary position, so that it's right-hand end may now

be placed to the left. If the bubble still continues to occupy the middle of the glass, the axis of the telescope is truly level or parallel to the horary circle; if not, alter the adjustment of the axis by the capstan screw, and of the level by it's own screws, till the bubble stands in the middle in both positions. 7. Set the semicircle of altitude to 90° , and fix it there; set the declination semicircle to 0° , and the horary index to VI. Direct the telescope to a remote object. Then move the horizontal circle half round, and set the horary index precisely at the opposite VI. If the same object be seen at the intersection of the cross wires, the line of sight is rightly placed, with respect to the horary index; if not, correct the axis of the telescope by the side capstan screw, so that the cross wires may cover an object halfway between the former object and that last seen. Lastly, make the horizontal and horary circles parallel to each other, and direct the telescope to a remote object, observing the degree and minute shewn by the nonius of the declination semicircle. Turn the horizontal circle 180° , and the horary index likewise 180° , and observe the same object. If the degrees and minutes on the declination semicircle be the same as before, the nonius is rightly placed; if not, take half the sum of the two altitudes, or depressions, which
will

will be the true altitude or depression of the object, with respect to the horary circle; then loosen the screws of the declination nonius, and move it till the object seen at the intersection of the cross wires gives the true quantity on the declination semicircle.

The problems wrought by the former instruments, with every other in astronomy, surveying, and mensuration, may be performed with singular accuracy by this equatorial.

F I N I S.



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C A T A L O G U E

O F

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Cylindrical ditto, from 1l. 1s. to — — —	13	13	0

Geographical and Astronomical Instruments.

PRICES OF GLOBES.

28 inches diameter, mounted in the common manner — — —	35	0	0
28 ditto mounted in mahogany frames — — —	50	0	0
28 ditto frames carved and ornamented — — —	6	6	0
18 ditto mounted in the common manner — — —	8	8	0
18 ditto mounted in the common manner in mahogany frames — — —	10	10	0
18 ditto mounted in the best manner, in stained frames — — —	12	12	0
18 ditto mounted in the best manner, in mahogany frames — — —	18	18	0

			£.	s.	d.
18	inches diameter, mounted in the best manner, in carved frames	— —	16	16	0
16	ditto	mounted in the common manner	6	6	0
12	ditto	mounted in the common manner	3	3	0
12	ditto	mounted in the common manner, in mahogany frames	— —	4	4
12	ditto	mounted in the best manner, in stained frames	— —	5	15
12	ditto	mounted in the best manner, in mahogany frames	— —	7	7
9	ditto	mounted in the common manner	2	2	0
9	ditto	mounted in the best manner	4	4	0
6	ditto	mounted in the best manner	3	3	0
3	ditto	mounted in the best manner	1	11	6
3	ditto	for the pocket	0	10	6
An armillary dialling sphere			40	0	0
An armillary sphere, shewing at one view the real and apparent motion of the heavens			31	10	0
An armillary sphere, with a planetarium within it			31	10	0
Plain armillary spheres					
A manual planetarium and tellurian			3	13	6
A new instrument for illustrating the phænomena of the seasons			— — —	4	10
A ditto for illustrating the phases of the moon, and the causes of eclipses			— —	4	10
A manual planetarium			— —	2	2
(The three last-mentioned instruments are those represented in plates V. XV. and XVI. of my astronomical essays)					
A planetarium with wheel-work, by which the order and motion of the planets, their situation with respect to the earth at different times, and the reason of their appearing to be sometimes stationary, and to move at other times in contrary directions, are rendered obvious to the eye				7	17
A tellurian and lunarium for illustrating the phænomena of the earth and moon, and forming a proper companion for the former					6
(The tellurian and lunarium may be combined together, or separate)					
A correct and elegant planetarium, lunarium, and tellurian, (see plate XIX. of my astronomical essays)			— —	18	18
Ditto with the diurnal motion to the earth			— —	24	0

	£.	s.	d.
The most complete planetarium, tellurian, and lunarium, plates XVII. and XVIII. —	36	15	0
Orreries, from 18l. 18s. to —	1000	0	0
A small quadrant, with an horizontal and vertical motion, for the instruction and amusement of young people — —	0	16	0
A ditto framed in brass, more accurately made and graduated — — —	2	12	6
A small equatorial, being at once an accurate universal dial, and a portable observatory; with it a great number of curious and interesting problems may be solved, and any person soon rendered master of the elements of practical astronomy — — —	8	8	0
Ditto on a larger scale, with a telescope, and more adjustments — —	26	5	0
Complete equatorial instruments, from 50 gs. to 500 —	0	0	0
Transit instruments, astronomical quadrants, circular instruments, according to their sizes, the variety and accuracy of their adjustments.			

Mathematical Instruments, for Geometry, Drawing, &c.

Plain compasses for measuring lines, from 1s. to —	0	5	0
Drawing compasses with moveable points, from 5s. 6d. to — — —	3	3	0
Drawing pens, from 1s. to — — —	0	5	0
Bow compasses for describing small circles, from 3s. to — — —	0	5	0
Hair compasses for taking extents with accuracy —	0	7	6
Beam compasses for describing large circles, laying down divisions, &c.			
Triangular compasses for transferring three points at once from any plan or drawing, from 18s. to —	1	1	0
Proportionable compasses for diminishing plans or drawing in any assigned proportions —	1	11	6
Elliptical compasses with friction rollers, for drawing ellipses — — —	4	4	0

	£.	s.	d.
Elliptical compasses on a different construction, answering at the same time the purposes of beam and calliper compasses	4	4	0
Spiral compasses for describing spirals, answering also as beam and elliptical compasses, from 6l. 6s. to	11	11	0
Parallel rules of various constructions			
A new-invented parallel rule, which for facility in application, and accuracy, exceeds any other kind, from 8s. 6d. to	1	1	0
Ditto with a protractor			
An instrument for drawing lines inclined in a given angle to each other, though the angular point is at an immense distance, a rule exceedingly useful in perspective			
Various instruments for the purpose of dividing lines, or transferring divisions on paper			
A cyclograph, or an instrument by which circles may be described, from 4 or 6 inches radius to one as large as the orbit of the Georgium Sidus	6	6	0
Plain scales and sectors of different sizes			
Square protractors, semicircular and circular			
Pocket cases of drawing instruments, from 7s. 6d. to	5	15	6
Magazine, or complete collection of drawing instruments, at 11l. 11s. at 17l. 17s. and from thence to	50	0	0
Perspective compasses for ascertaining the relative proportion of objects	0	18	0
Dr. Hirst's instrument for drawing in perspective	5	5	0
A new invented instrument for the same purpose, which will facilitate the operations of the artist, and greatly assist beginners			
An instrument for facilitating drawing from nature, by ascertaining a number of points			
Concave lenses with squares for eye drafts			
Drawing glasses, or glasses with a sight to assist draftsmen			
Pantographers for copying, reducing, and enlarging drawings, from 2l. 12s. 6d. to	6	6	0

Surveying Instruments.

£. s. d.

Cases of drawing instruments			
Parallel rules			
Plotting scales			
Sets of plotting scales			
A new-invented parallel rule, with plotting scales			
A parallel rule and protractor			
A plotting scale, in form of a beam compass			
Protractors for laying down angles			
Ditto with a nonius and moveable limb	—	2	12 6
Ditto rendered more accurate, as the limb is made to move with a tooth and pinion	—	4	14 6
Measuring wheels	—	6	16 6
Pedometers for measuring a given distance in walking.			
Measuring chains of 50 and 100 feet			
Gunter's chain	—	0	7 6
Tape boxes, according to the length	—	1	11 6
Surveying crosses or square	—	3	13 6
Plain tables, with an index and sights; by these the plan is taken on the spot, and does not require a future protraction	—	14	1 40
Brighton's improved plain table, with an index of a peculiar make; in this instrument the line of sight is always over the center of the table, the station lines are also drawn parallel to those measured on the ground	—		
Theodolites, or instruments for measuring angles, distances, &c. are made in various ways, some being more simple and portable, others more accurate, and with a greater number of adjustments.			
Theodolites, with four plain sights, and a compass box, from 5l. 5s. to	—	5	15 6
A small theodolite, with telescopic sights and vertical arch	—	9	9 0
A larger ditto, in which the limb of the theodolite is made to serve occasionally the purpose of a protractor	—	14	14 0
A ditto of the same size, on a different construction, the vertical arch being affixed to a long axis; the limb does not serve for a protractor	—	14	14 0
A larger ditto, like the preceding, only moving with rack-work	—	21	0 0

£. s. d.

The latest improved theodolite, with double telescope, and every requisite adjustment			
Circumferenters, the principal instrument used in America, from 2l. 2s. to —	4	14	6
An improved circumferenter, so contrived, that the operator need not rest the truth of his work entirely on the needle; it may be also used to take altitudes			
Air or spirit levels with telescopic sights, from 4l. 14s. 6d. to —	12	12	0
Air or spirit levels with plain sights —	1	11	6
Station staves with sliding vanes for levelling	1	16	0
A small surveying compass, with sights, a nonius division, and three-legged staff —	4	14	6
A small surveying compass and single stick	2	2	0
(The two foregoing instruments are portable and light, and may be put with ease in the pocket)			
Miners compasses, used for carrying on works under-ground, from 10s. 6d. to —	1	1	0
Ditto with a small telescope fixed to one side	1	11	6
Green's telescope and tangent board, for measuring distances at one station: (it is obvious, that on the measuring of a strait line with accuracy, the whole business of surveying depends; Mr. Green's method is certainly more expeditious than any other, and is not liable to objections which may be made to them)			
Optical square, a small instrument for surveying by right angles; it requires no staff, and may be easily corrected or adjusted — —	1	16	0
An optical instrument for determining with accuracy when objects are in a strait line —	1	7	0

Military Instruments.

Gunners levels or perpendiculars
 Gunners callipers
 Beam callipers
 Shot gauges
 Shell ditto
 Gunners quadrants with a plummet
 Ditto with a level

Ditto

Ditto with an adjusting screw	£.	s.	d.
Ditto and perpendicular combined together			
General Williamson's instruments for howitzers, mortars, &c.			
Surveying compasses, surveying crosses, cases of instruments, telescopes, plain tables, theodolites, &c.			
A complete apparatus for an officer, in a box	21	0	0

Instruments for Navigation.

Cases of Instruments, and telescopes of different kinds, sizes, and prices			
Night telescopes, from 1l. 11s. 6d. to	2	2	0
Opera glasses for the same purpose	1	11	6
A telescope with an eye-glass micrometer, for determining the distance of a ship at sea			
Hadley's quadrants in mahogany frames	2	2	0
Ditto in black ebony frames	3	3	0
Hadley's sextant in wood	6	16	6
Ditto in brass, on the most improved plan, from 11l. 11s. to			
Knight's steering compass, with improvements	15	15	0
Knight's azimuth ditto	2	12	6
Ditto on friction wheels	5	15	6
Marine barometers; by these storms have been foretold at sea some hours before they happened	10	10	0
Circular instruments, to answer the purpose of the sextant			
Dipping needles, from 12l. 12s. to	31	10	0

Instruments for Electricity.

A small electrical machine, with a select apparatus	8	8	0
An electrical machine and medical apparatus in a box; the machine is mounted in a plain but strong manner, and so as to act with power; the apparatus is the most convenient and simple hitherto contrived for medico-electrical purposes	6	16	6

	£.	s.	d.
Ditto with an additional apparatus lately contrived for inore easily giving partial shocks —	7	17	6
Improved electrical machines, from 3l. 13s. 6d. to 40	0	0	0
Electrical batteries, from 2l. 12s. 6d. to			
Electrical jars of different sizes			
Ditto with an electrometer affixed to them	0	18	0
Medical bottles, with a tube for qualifying the shock — — —	0	7	6
Ditto mounted with a discharging rod, and an electrometer, on an improved plan, for giving the electric shock — — —	1	1	0
Directors with glass handles for medical purposes	0	10	6
Jointed dischargers with glass handles —	0	10	6
Plain discharging rods — —	0	3	0
An universal discharger and press —	1	11	6
Kinneally's electrical thermometer —	1	1	0
Quadrant electrometer — —	0	10	6
Cavallo's atmospheric electrometer, from 15s. to	1	1	0
Ditto with additions by De Saussure —	1	11	6
Bennet's gold leaf electrometer —	0	18	0
An apparatus for making Canton's and Willson's experiments on electric attraction, &c.			
Compound apparatus, fig. 49, plate III. of my essays on electricity; by this apparatus a great number of neat and satisfactory experiments may be performed — —	3	3	0
Ditto without the exhausted flask and conductor	1	11	6
Leyden vacuum — — —	0	10	6
Luminous conductors — — —	1	1	0
Spiral tubes, from 4s. 6d. to — —	0	10	6
Coloured spirals — — —	0	9	0
Sets of spirals, see plate V. fig. 98, of my essays on electricity — — —	1	11	6
Luminous words, from 10s. 6d. to — —	1	11	6
Spotted bottle — — —	0	9	0
Belted bottle, plate III. fig. 45 — — —	1	1	0
Double bottle, a pleasing and useful part of an electrical apparatus, to gain a clear idea of the Franklinian theory — — —	0	18	0
Plates and stand for dancing images, pith images, and pith balls			
An artificial spider			
A small head with hair			
An electrical pistol for inflammable air —	0	7	6
Ditto mounted in sets			

	£.	s.	d.
An electrical cannon for gunpowder			
A thunder house	0	6	6
Ditto with a drawer	0	8	6
A powder house, fig. 89, plate V.	0	16	0
A pyramid, fig. 90, plate V.	0	15	0
Nicholson's revolving doubler	3	3	0
A bone ball and a ball of box wood fitted on brass wires			
Electric flyer and points			
A plain set of bells, fig. 17, plate II.	0	9	0
Five bells mounted on a stand, fig. 18, plate II.	0	18	0
A set of musical bells, fig. 19, plate II.	1	7	0
Magic picture	0	10	6
Electrical stools, from 8s. 6d. to			
An electrophorus, from 10s. 6d. to			

Apparatus for Experiments on Magnetism.

An apparatus for explaining the principal phenomena of magnetism, from 3l. 3s. to	15	15	0
Magnets			
Small compound magnets			
Horseshoe magnets			
Compound ditto, from 15s. to	21	0	0
Dipping needles from 12l. 12s. to	31	10	0
Variation compasses, from 2l. 12s. 6d. to	21	0	0

Instruments for Experiments on Pneumatics.

A small single-barrel air-pump	2	12	6
A small double-barrel ditto	4	14	6
A larger ditto	6	16	6
A table air pump	10	10	0
The American double barrelled air pump, the latest improvement on this instrument, in which the air receives no impediment from the action of valves or cocks, exceeding Smeaton's in accuracy and simplicity, and far superior in both respects to several later contrivances			

£. s. d.

A condensing engine; this may be, if desired, combined with the former, but the rational and practical experimentalist will find many advantages in having them detached from one another

Apparatus for an Air Pump.

The magdeburg hemispheres, from 12s. to	1	11	6
A flat plate and collar of leathers for placing on open receivers	0	15	6
Guinea and feather apparatus, for experiments on the resistance of the air, from 18s. to	1	11	6
A set of mills for ditto	1	11	6
A ditto on a better construction	4	4	0
Bell apparatus, for shewing that a vacuum does not communicate sound	0	5	6
Ditto on a better construction			
Ditto with wheel-work, by which the bell may be put in motion or stopped at pleasure	3	13	6
A new apparatus for striking flint and steel in vacuo			
An apparatus for firing gunpowder in vacuo			
A copper bottle, beam and stand, for weighing of air	2	16	0
A box bladder and lead weights, to shew the elastic power of the air	0	15	6
Ditto on an improved plan	0	18	0
A model of a pump, illustrating at the same time the nature of pumps, and proving that there is no such thing as suction	1	5	0
A small receiver and plate, which clearly evinces that receivers are kept on the pump by pressure, not suction	0	12	0
A filtering cup	0	5	6
A plate and piece of wood	0	4	6
(The two last articles are for shewing the porosity of vegetables)			
The torricellian experiment			
Fountain in vacuo	0	5	6
Ditto on a different construction	0	18	0
Lungs glass	0	5	6
Ditto on a different construction			
A single transferer plate and pipe for a fountain	0	15	6

A double

	£.	s.	d.
A double transferer, for communicating a vacuum from one receiver to another	—	3	3 0
A burnt air pipe, for experiments on infected air	0	18	0
An apparatus to illustrate the lateral pressure of the air			
Breaking square and cage			
A small bladder and lead weight			
A small balance beam and stand	—	0	7 0
Ditto on an improved construction			
Receivers of different sizes			

Meteorological Instruments.

A plain portable barometer	—	2	2	0
Ditto with a thermometer	—	3	3	0
A plain barometer, covered frame and glass door		2	12	6
Ditto with a thermometer	—	3	13	6
A barometer with a long cylindric thermometer		4	4	0
A ditto with ditto, and De Luc's hygrometer		7	7	0
A barometer and thermometer, with a gauge, the indexes moving by rack-work	—	5	15	6
A barometer for measuring the altitude of mountains, &c.				
Marine barometers				
Diagonal, wheel, and statical barometers				
Fahrenheit's thermometers, from 1l. 1s. to		2	12	6
Ditto for botanic purposes	—	0	18	0
Ditto for the brewery	—	1	1	0
De Luc's hygrometer; these are the only instruments by which comparative observations can be made on the dryness and moisture of the air, from 3l. 3s. to	—	7	7	0
Rain gauges				
Dr. Lind's wind gauge				
Hygrometers with the beard of the wild oat		0	10	6
Fontana's eudiometer for ascertaining the purity of the air	—	2	5	0

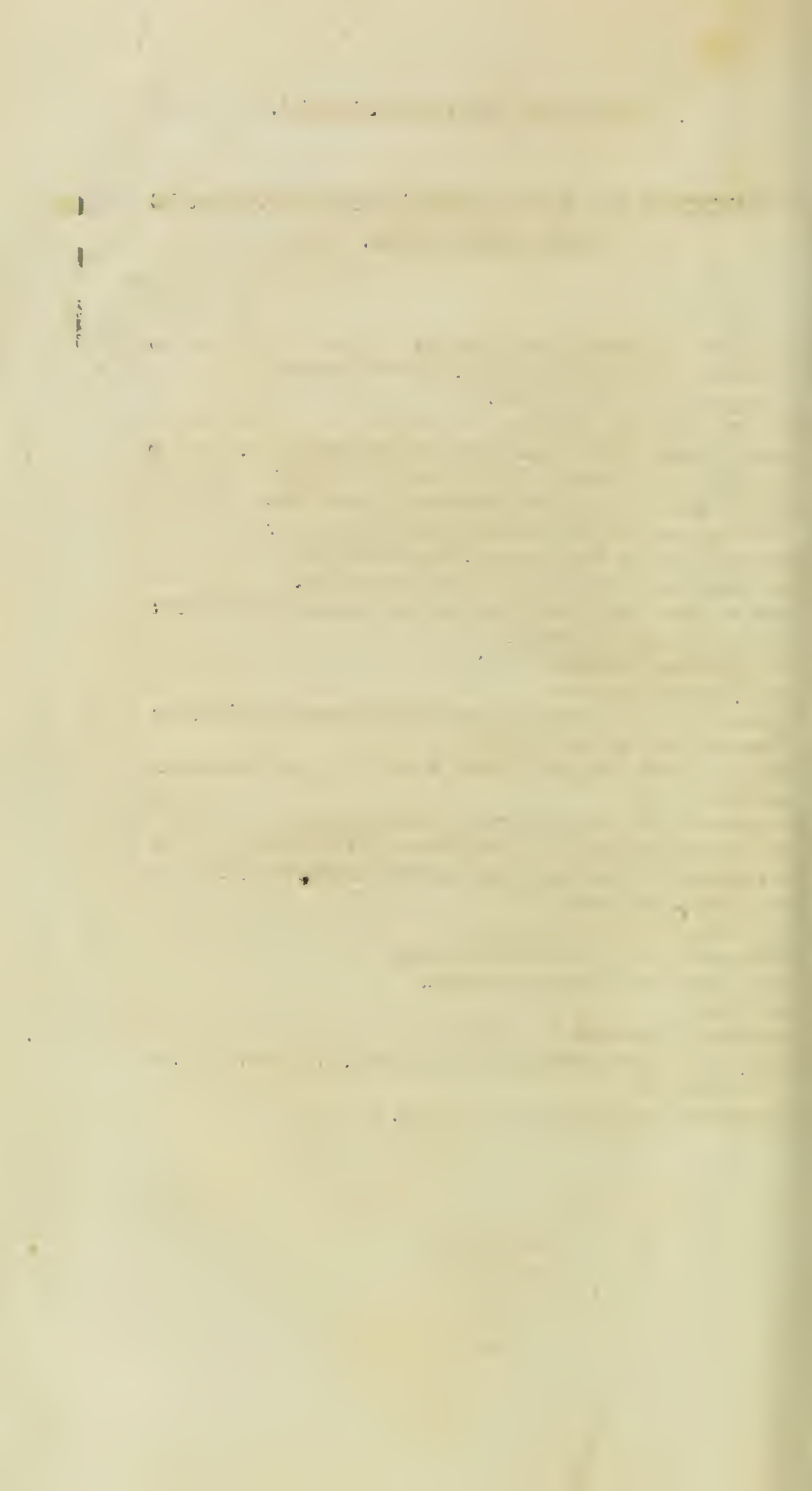
Instruments for illustrating the Mechanic Powers, the Laws of Motion, &c.

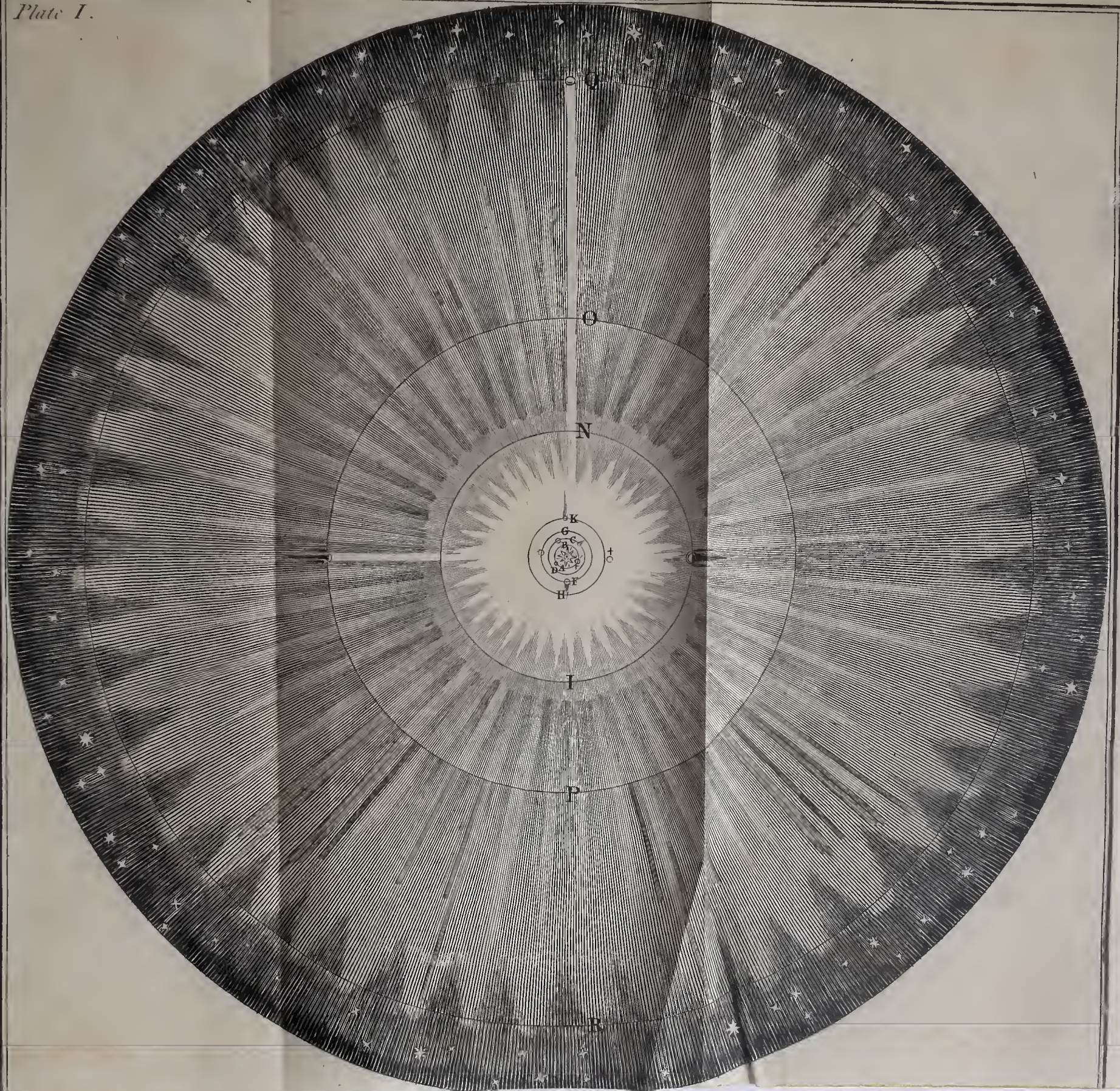
- | | £. | s. | d. |
|--|----|----|----|
| A concise apparatus for illustrating the nature of the ballance, the pulley, the different kinds of levers, the inclined plane, the wheel and axle, the screw, a compound engine, and a compound lever; also, a double cone to move up an inclined plane, and other pieces to shew the properties of the center of gravity, from 21l. to | 26 | 5 | 0 |
| A ditto on a more enlarged scale | | | |
| Atwood's apparatus for demonstrating with accuracy the laws of accelerated and retarded motion. It is one of the most pleasing and scientific instruments in mechanics, as well from the variety of experiments that may be made with it, as the accuracy with which they are performed | 26 | 5 | 0 |
| A machine for illustrating the theory of central forces; in this machine the times are marked by sound, the spaces are shewn by an index, the errors arising from friction are so far lessened as to be scarcely sensible | 31 | 10 | 0 |
| Pullies of various combinations and constructions | | | |
| A small carriage, inclined plane, wheels of different sizes, &c. for experiments on wheel carriages | | | |
| Roberval's paradoxical ballance | | | |
| Cycloidal lever, see Emerson's Mechanics, prop. 20, 25. | | | |
| Compound steelyard | | | |
| An apparatus for experiments on collision | | | |
| Ditto for illustrating the composition and resolution of motion | | | |
| Pyrometers on various constructions | | | |
| With many other articles and models for experiments on friction, pendulums, &c. too numerous to be comprized in a small catalogue | | | |

Instruments for Experiments in Hydrostatics and Hydraulics.

	£.	s.	d.
Hydrostatic ballances, from 2l. 2s. to —	10	10	0
Nicholson's improved hydrometers, for ascertaining the specific gravity of bodies			
Ditto for examining of coin			
A concise apparatus for experiments on hydrostatics	21	10	0
An apparatus for shewing that fluids have weight			
Ditto for shewing that the particles of fluids exercise their pressure independently one of the other			
Ditto to shew that fluids press in every direction			
Ditto to demonstrate the lateral pressure of fluids			
Ditto to shew that, <i>cæteris paribus</i> , the pressure of fluids is as their perpendicular height			
The hydrostatic paradox			
The hydrostatic bellows			
Apparatus for illustrating the laws of pressure and equilibrium between heterogeneous fluids			
Ditto for illustrating the action of fluids upon bodies immersed in them			
An apparatus for experiments on spouting fluids			
Hydrometers for proving spirits, from 1l. 11s. 6d. to 4	14	0	0
An apparatus for making experiments on capillary tubes			
The model of the diving bell			
A glass model of the lifting pump			
A ditto of the lifting and forcing pump			
Hiero's fountain in copper japanned			
Ditto double			
Fountain of command			
A japanned copper fountain to act by condensed air with a variety of jets			
Apparatus for experiments on syphons.			







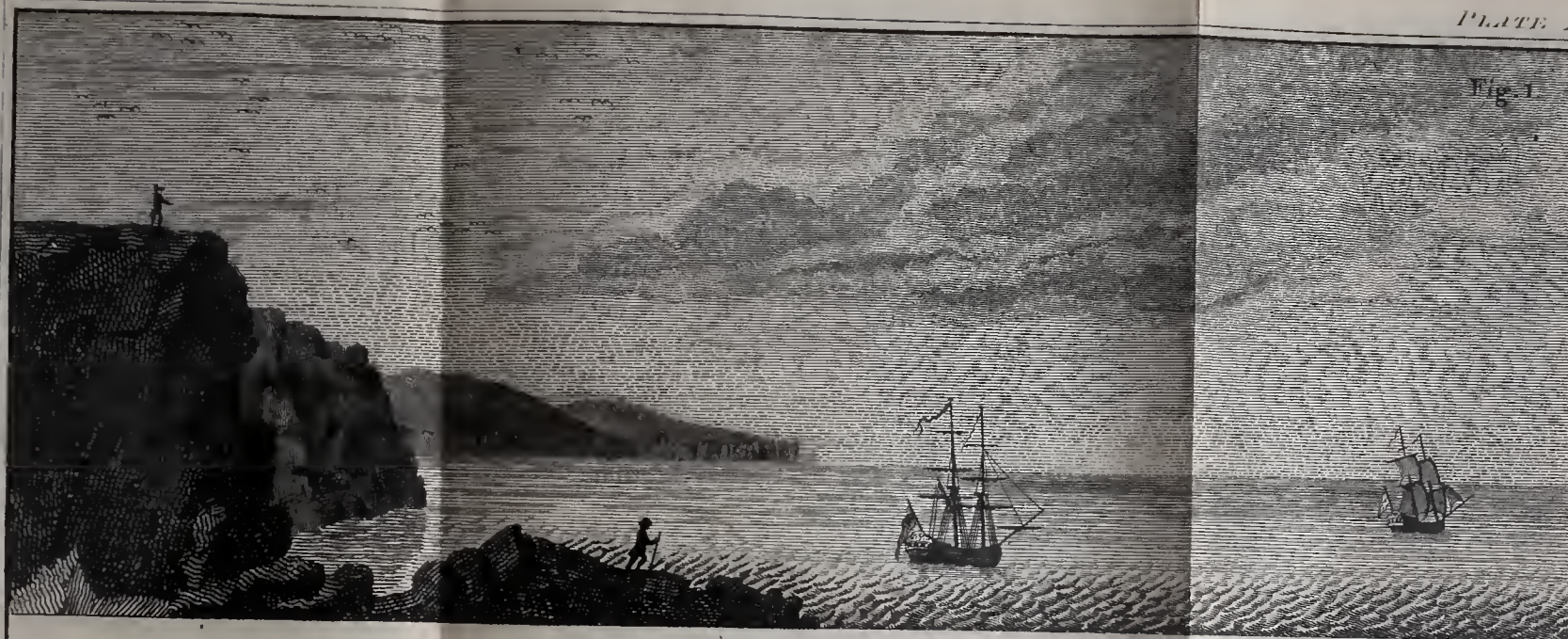


Fig. 1.

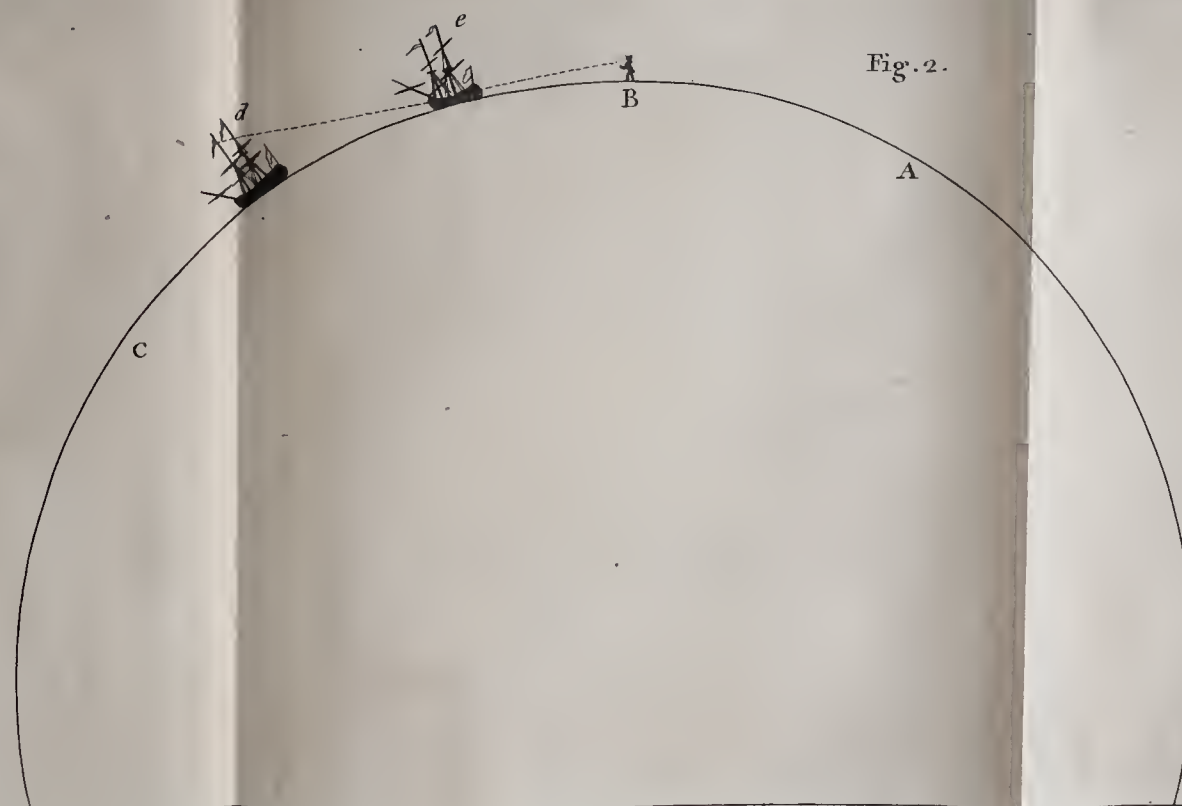


Fig. 2.

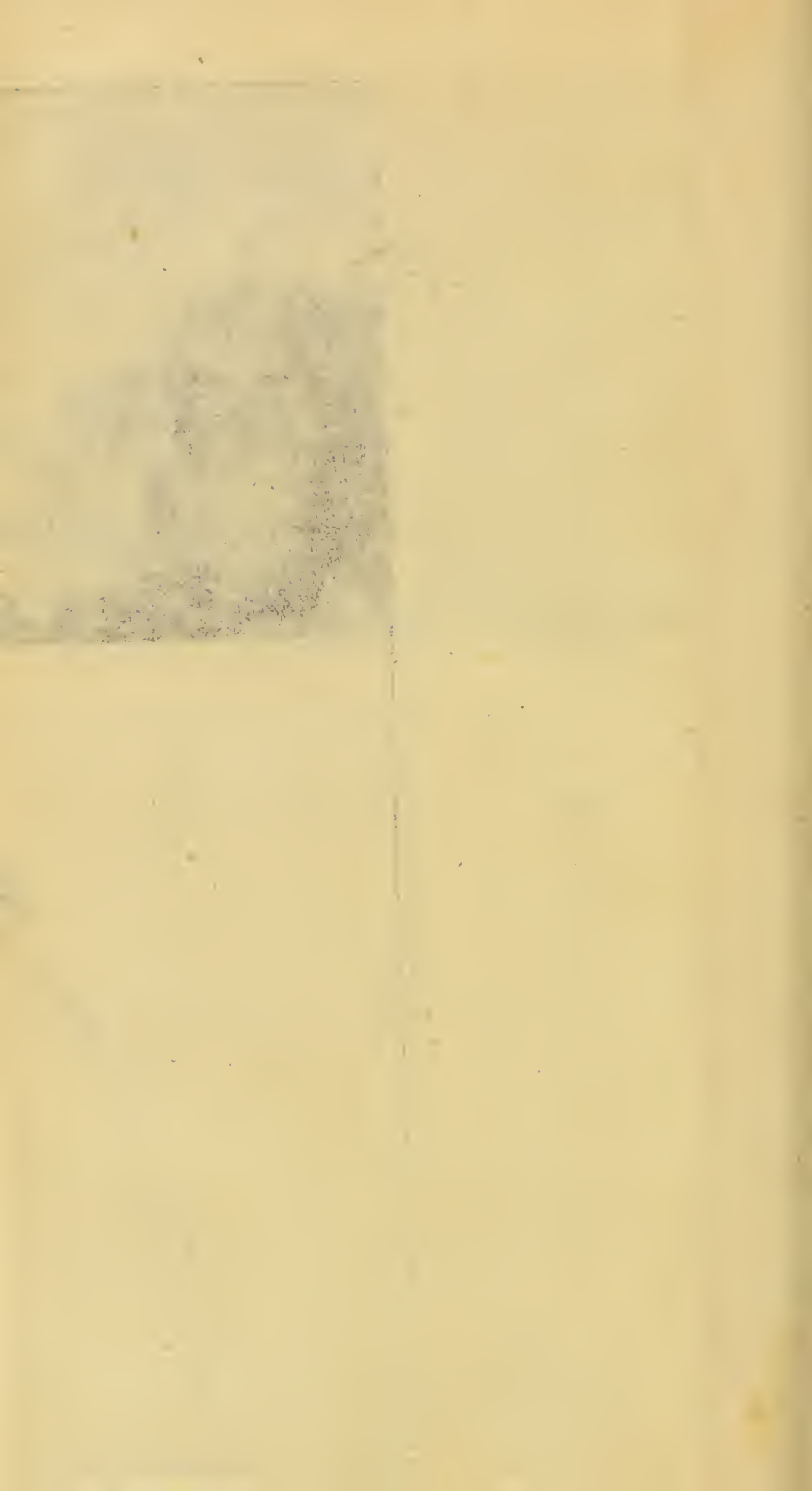


Fig. 1.

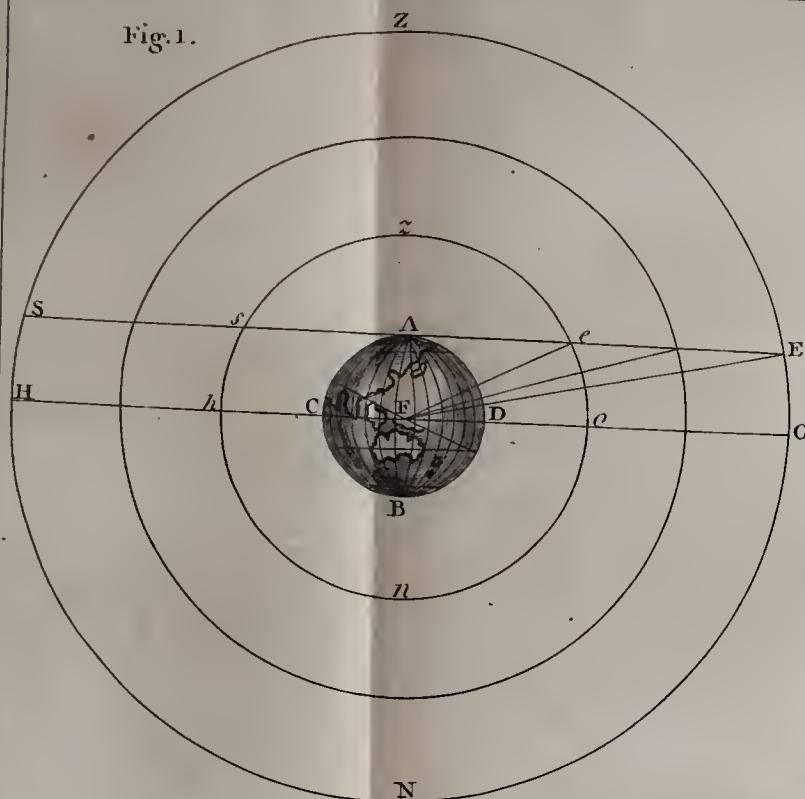


Fig. 2.

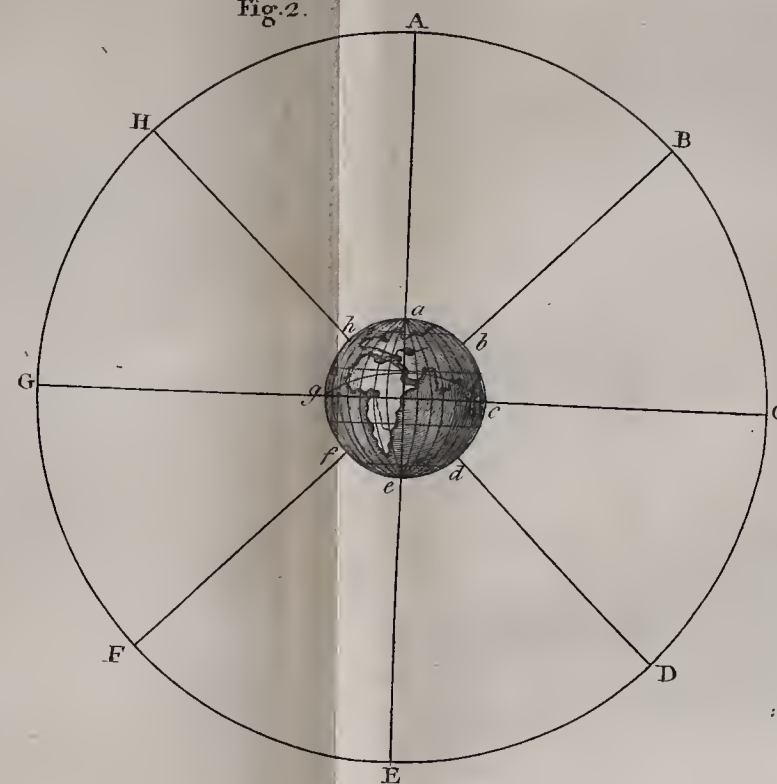


Fig. 3.

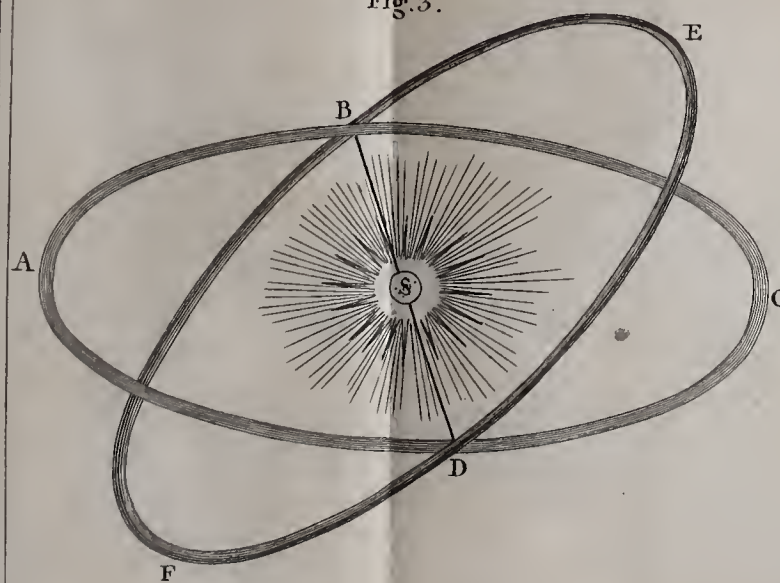


Fig. 4.

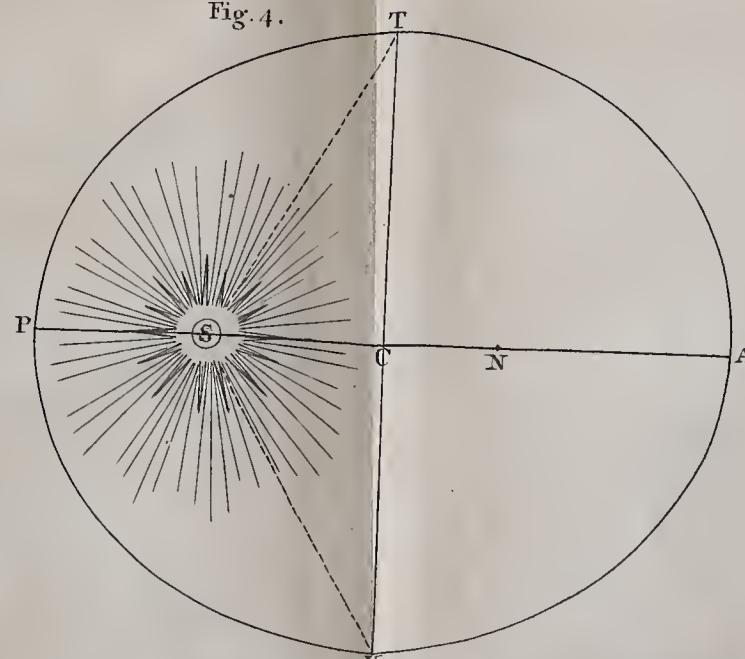


Fig. 1.

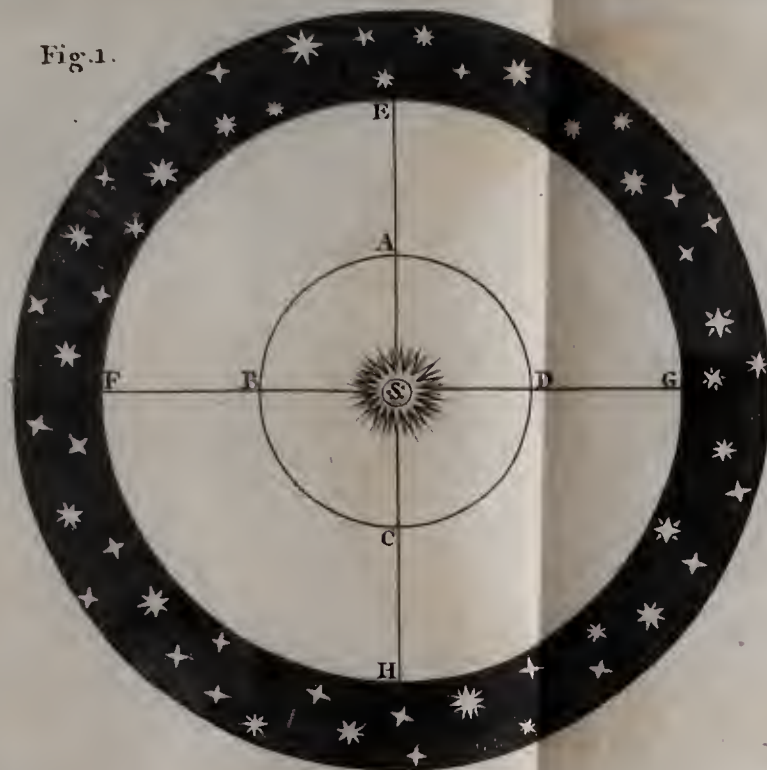


Fig. 2.

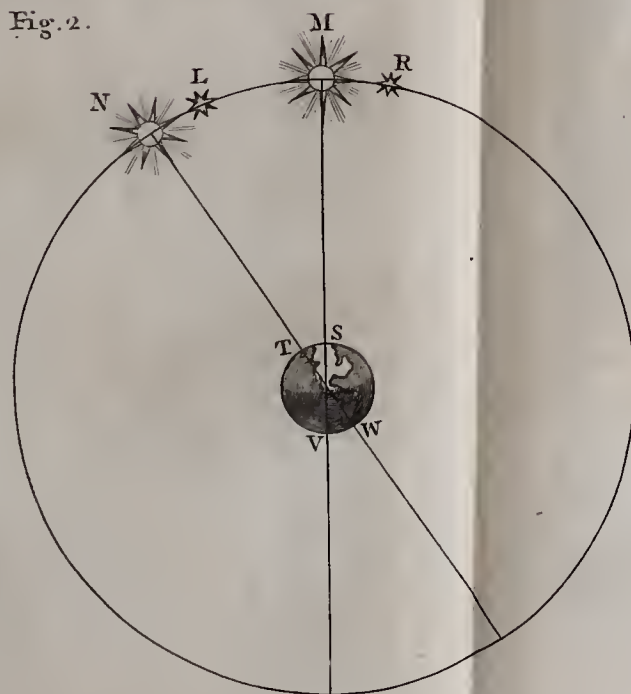


Fig. 3.

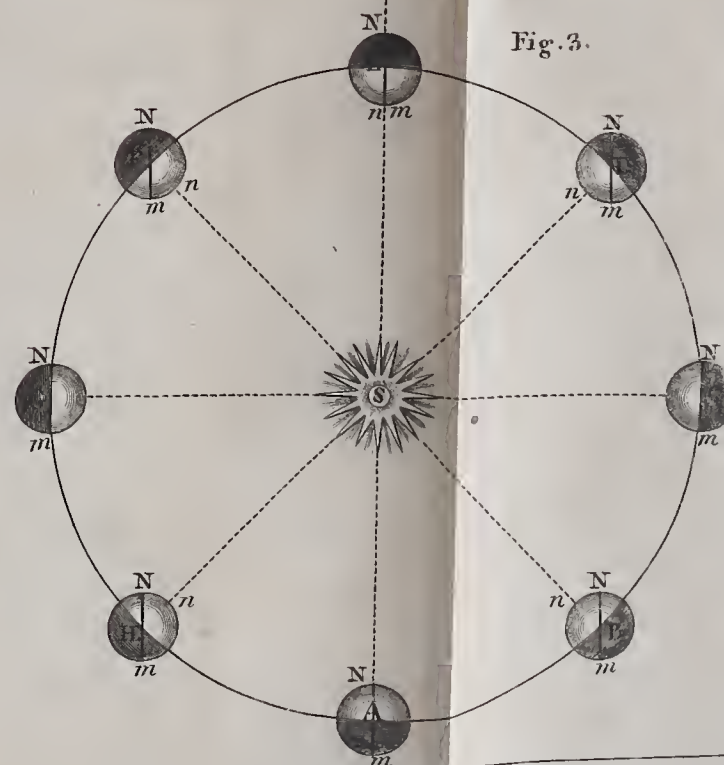


Fig. 1.

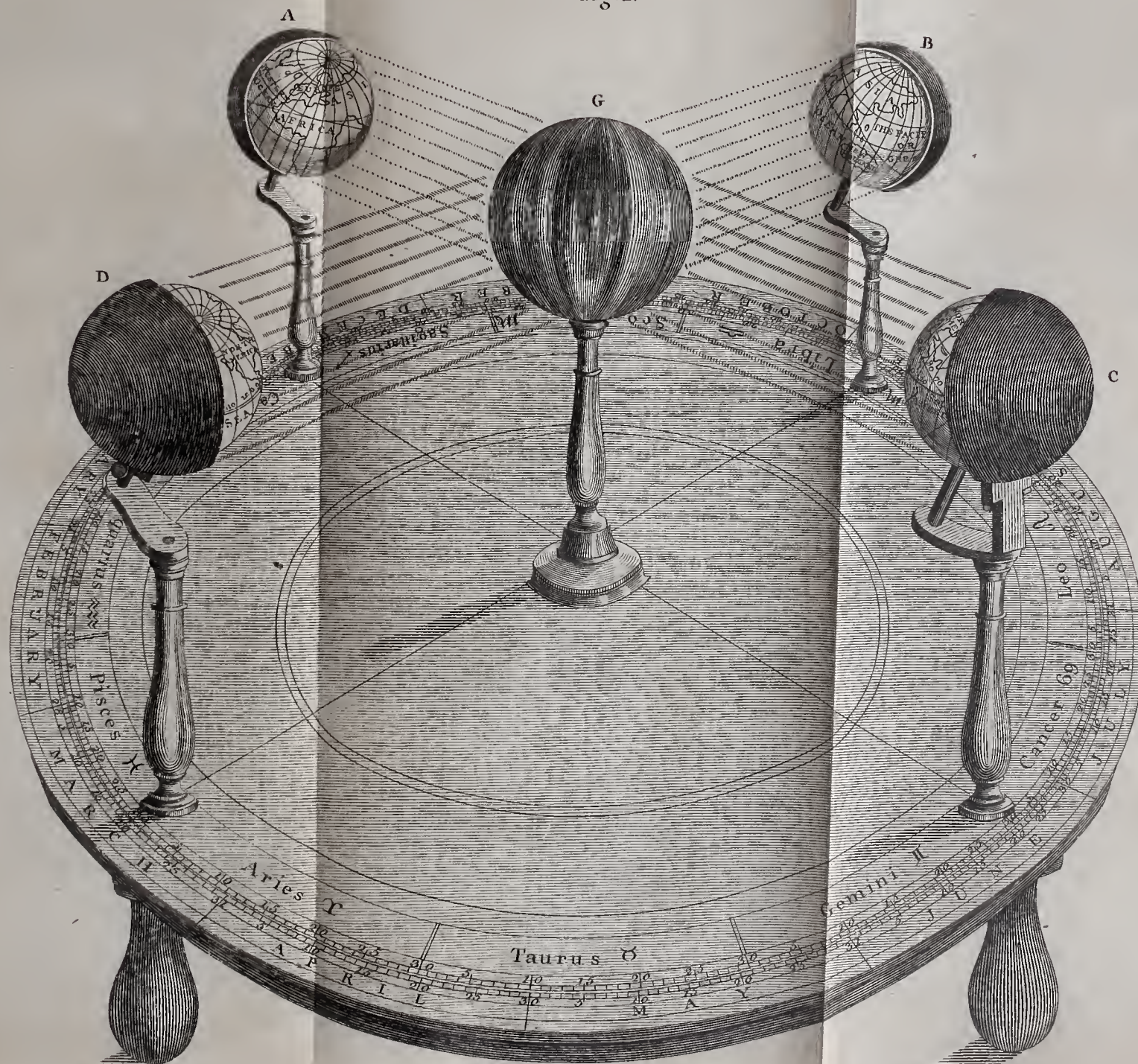


Fig. 1.



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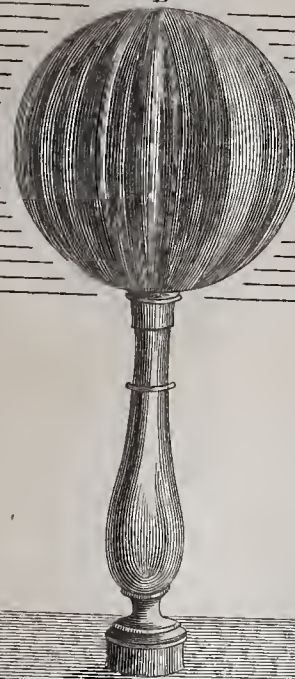


Fig. 2.

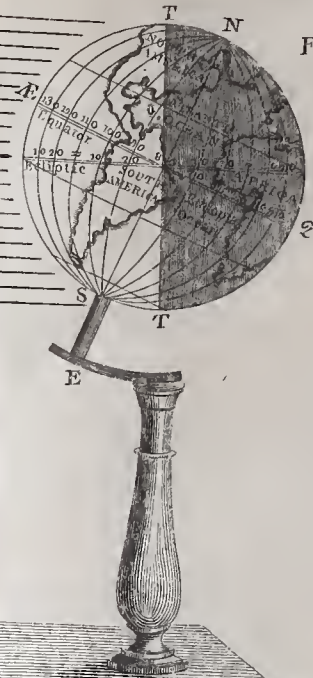


Fig. 3.



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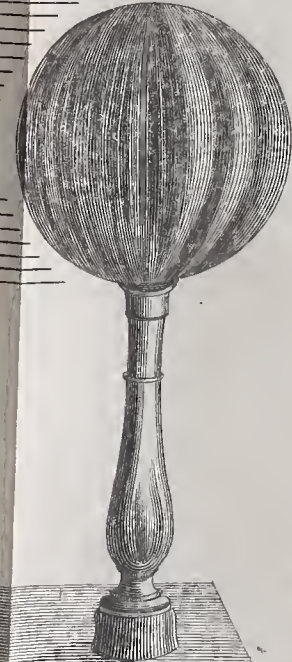


Fig. 1.

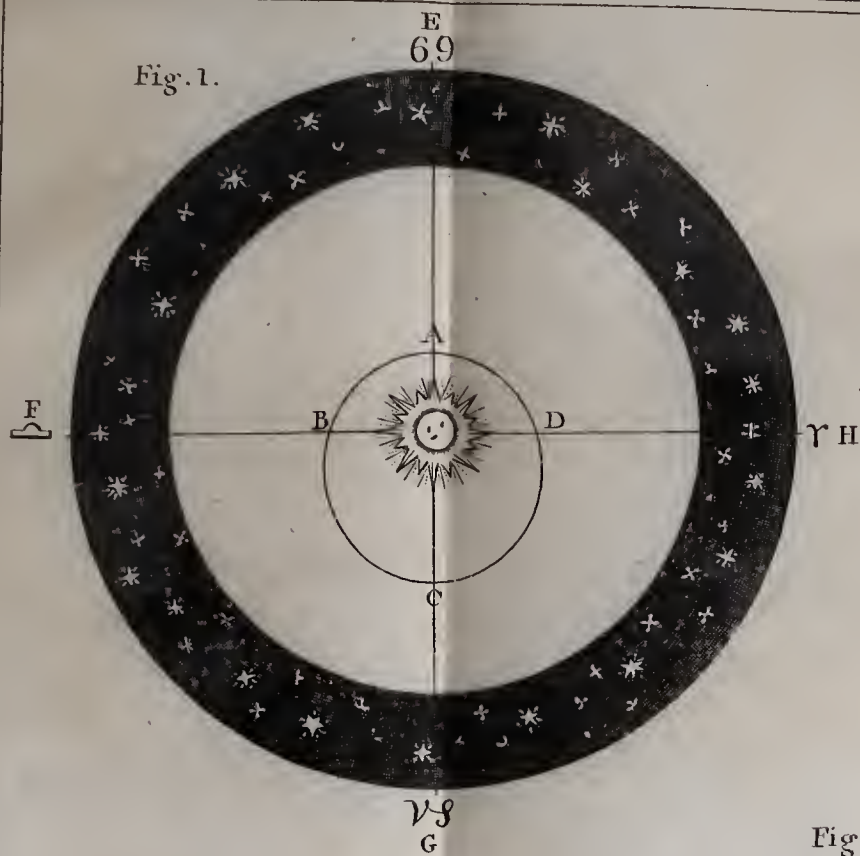


Fig. 3.

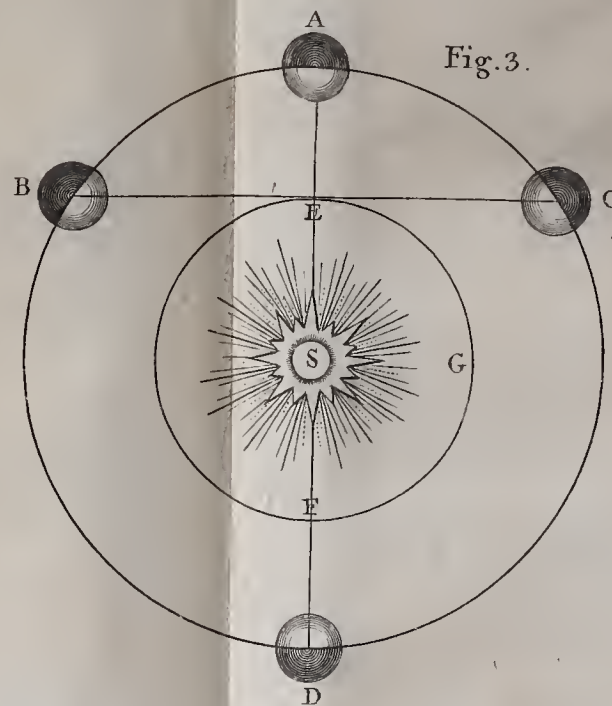
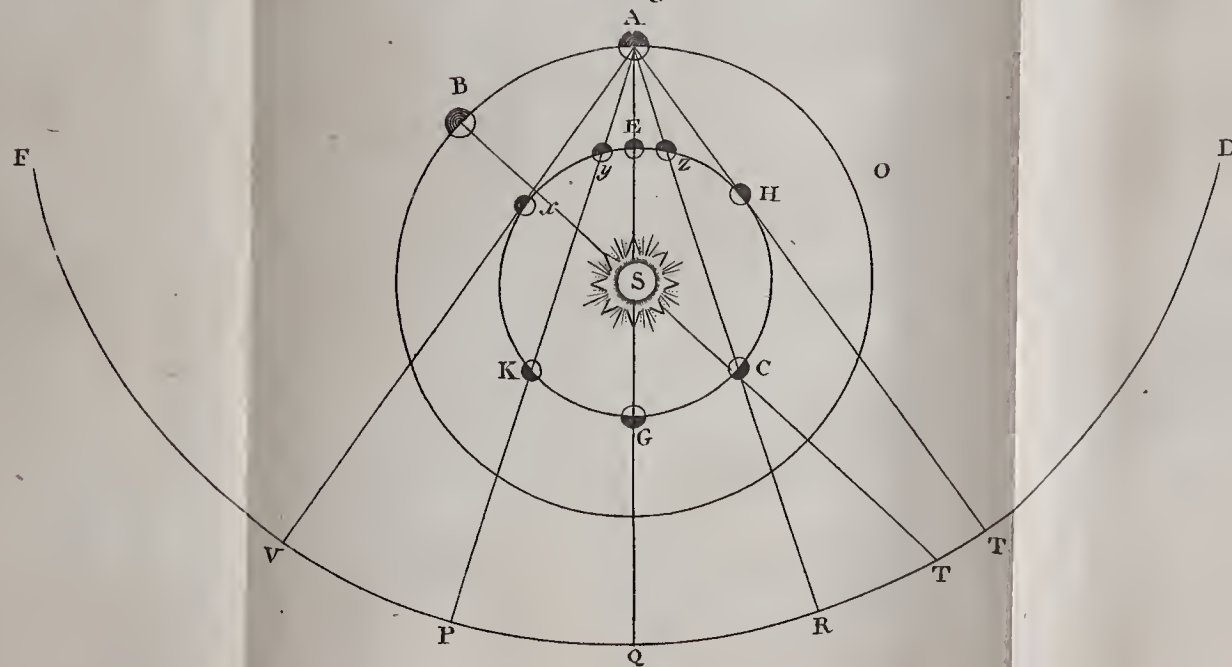


Fig. 2.



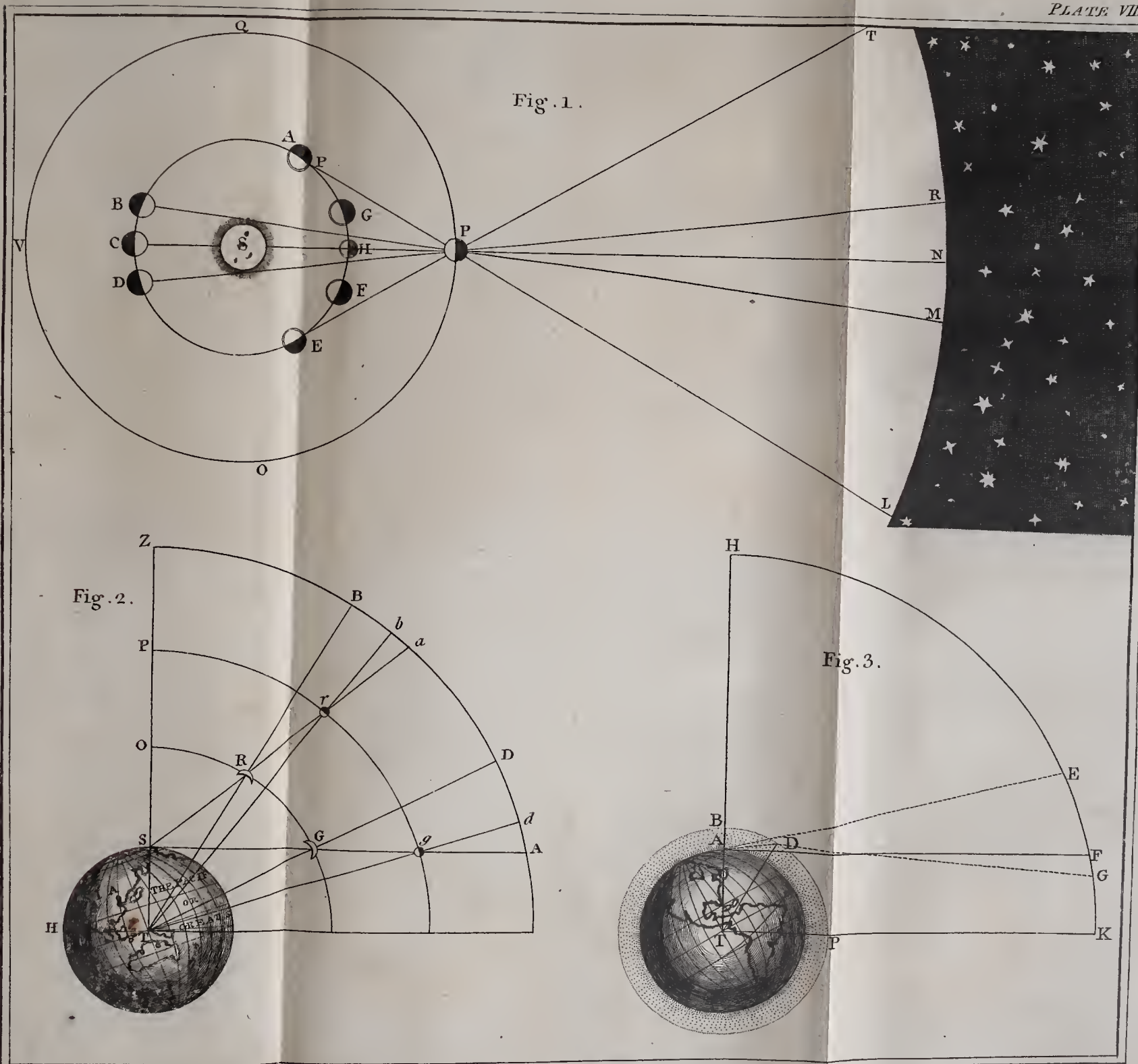




Fig. 1.

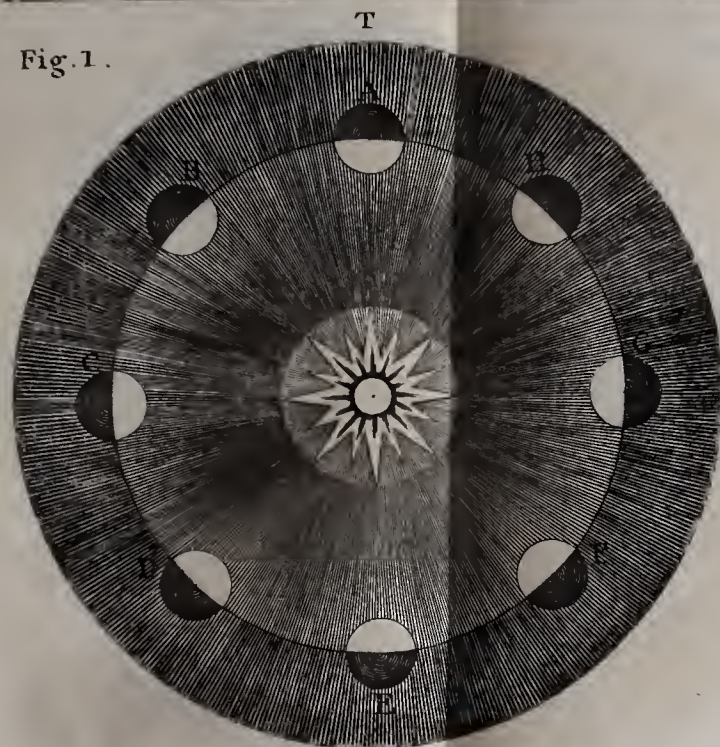


Fig. 2.

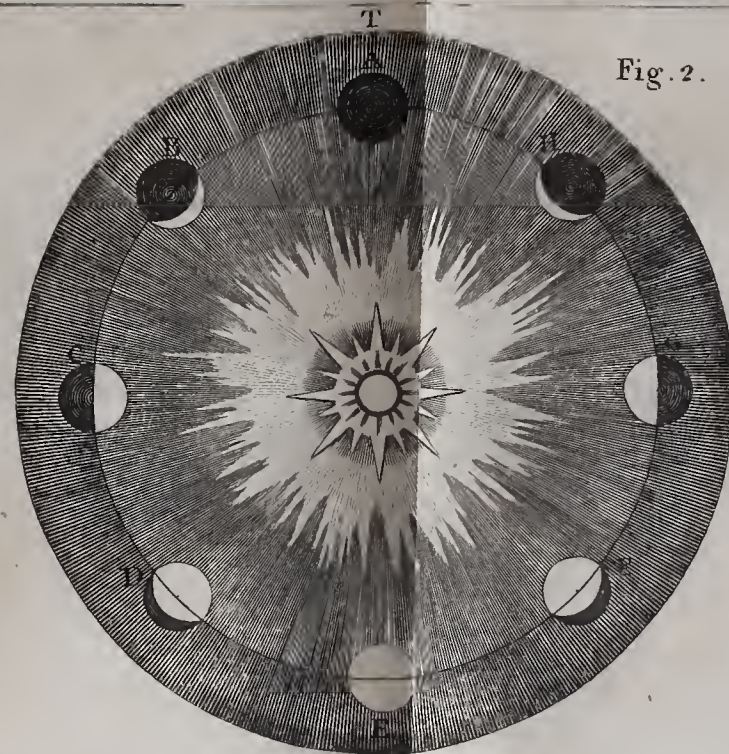


Fig. 4.

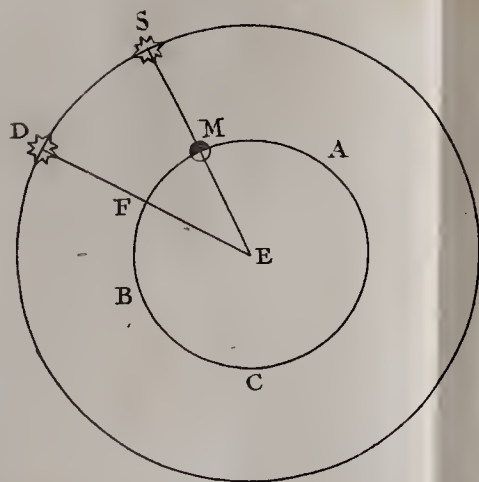


Fig. 3.

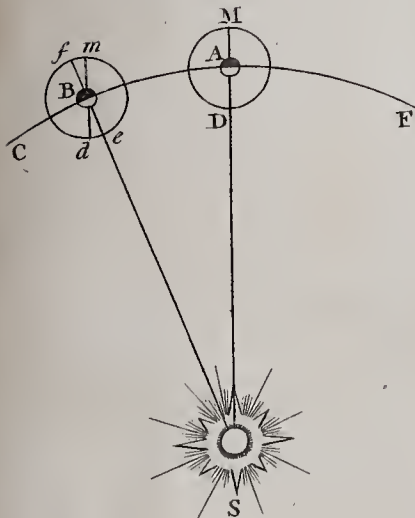


Fig. 7.



Fig. 6.

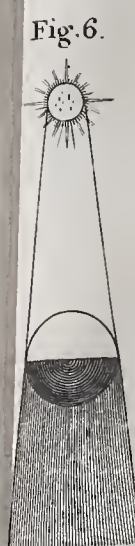


Fig. 5.



Fig. 1.

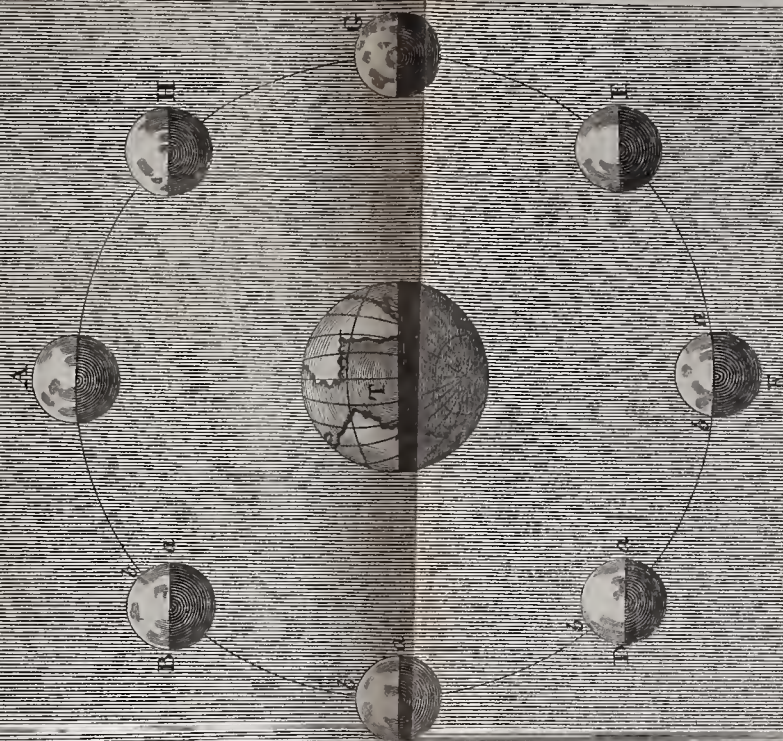
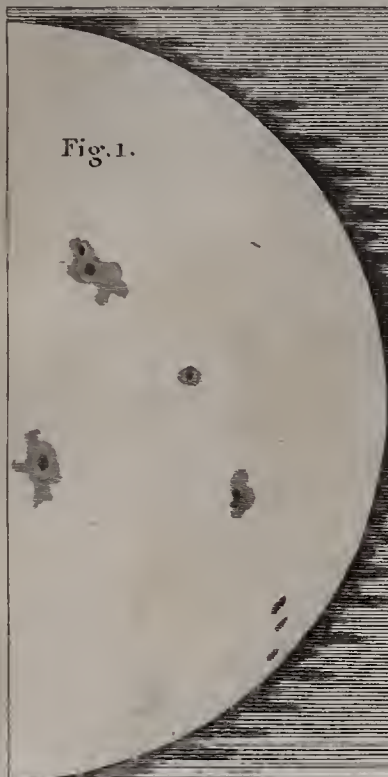


Fig. 2.

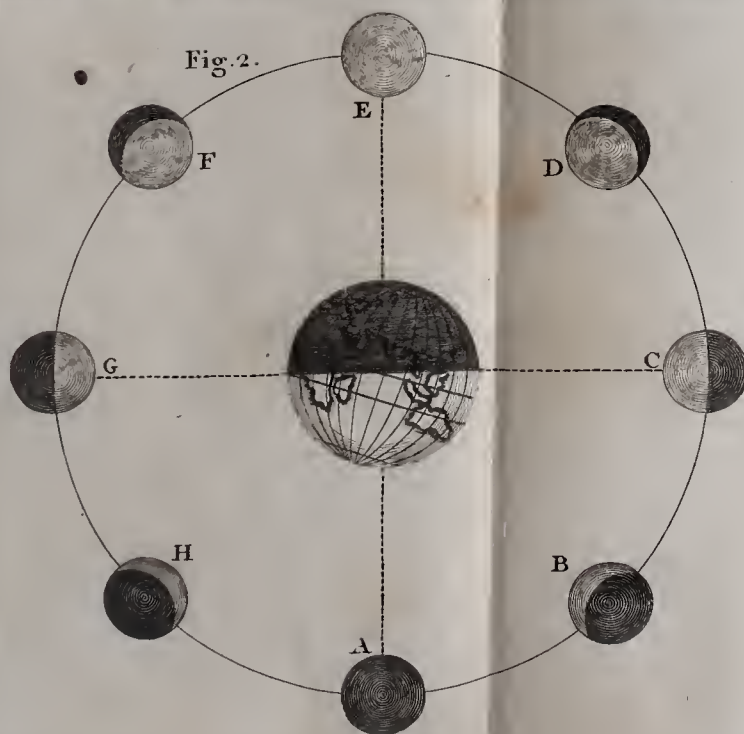
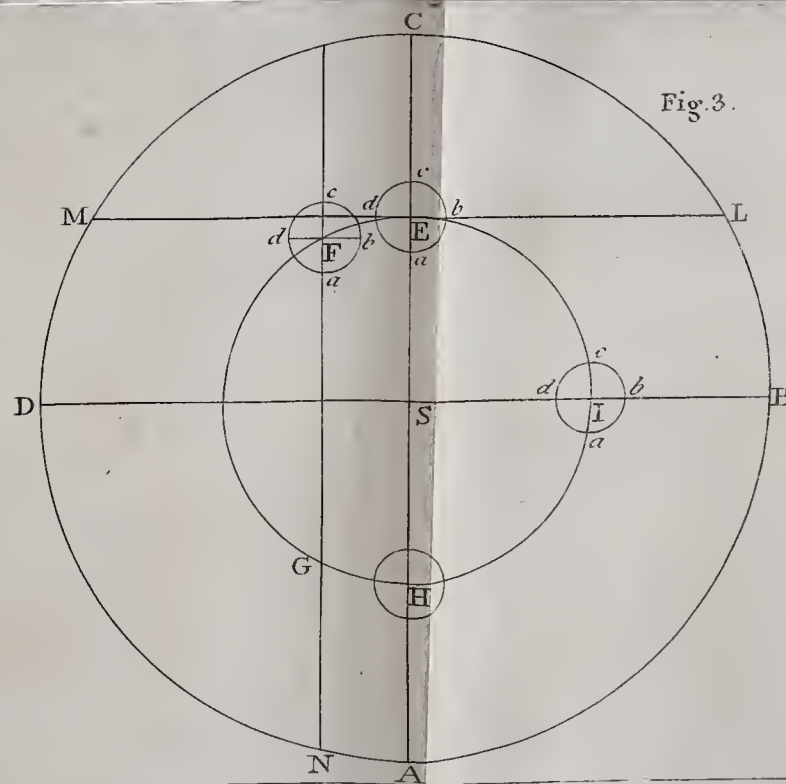


Fig. 3.



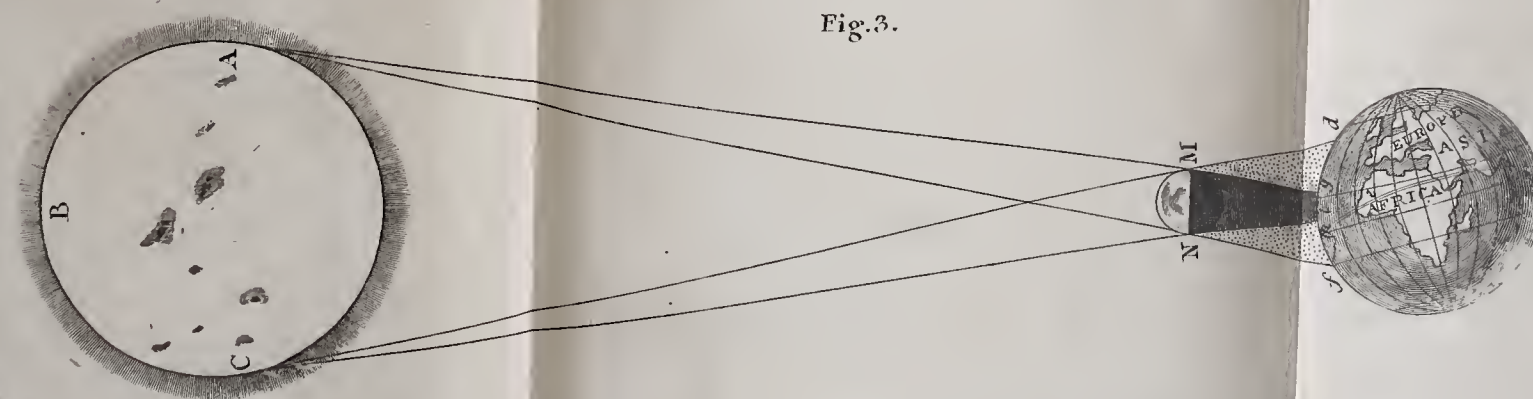
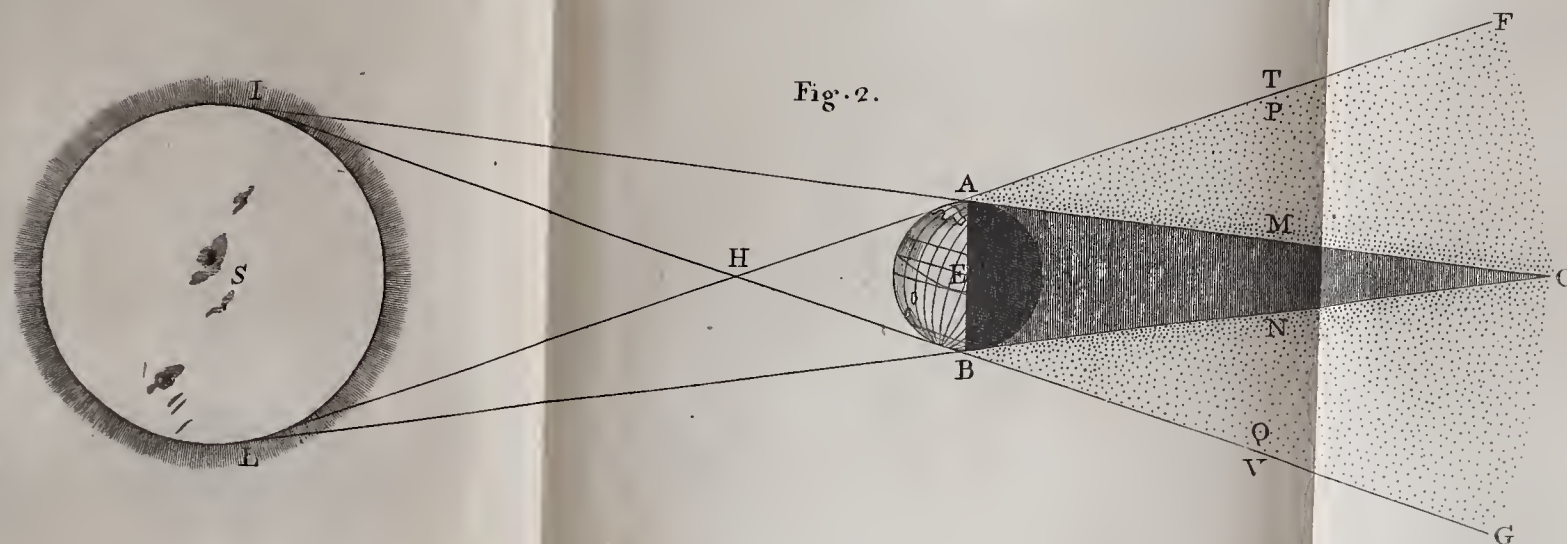
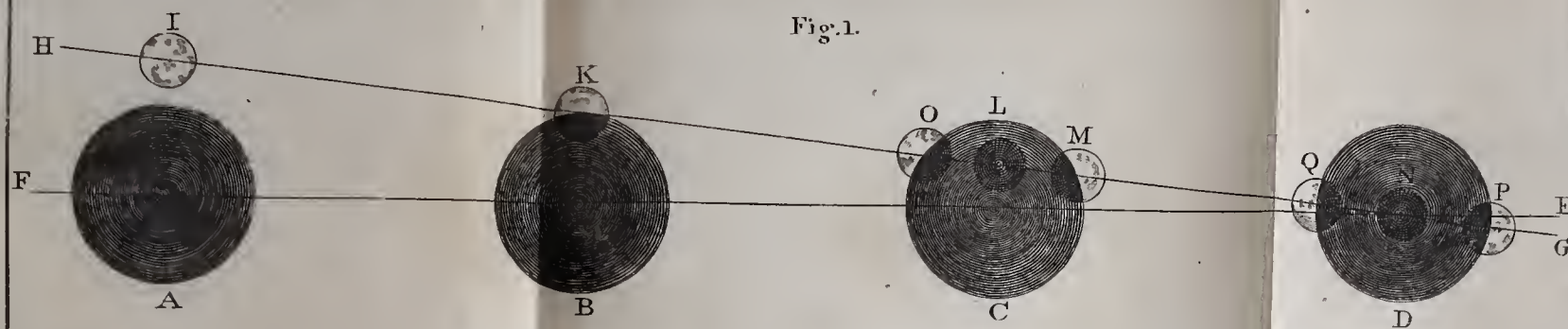


Fig. 1.

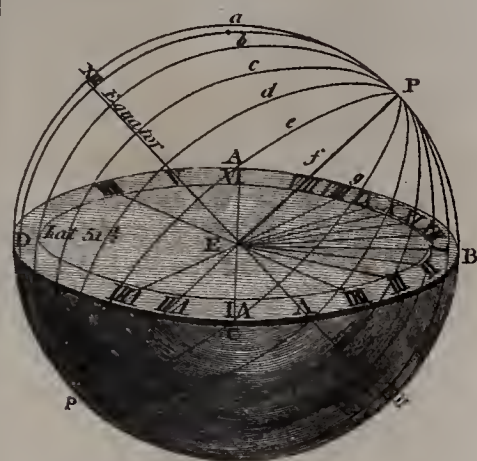


Fig. 2.



Fig. 5.

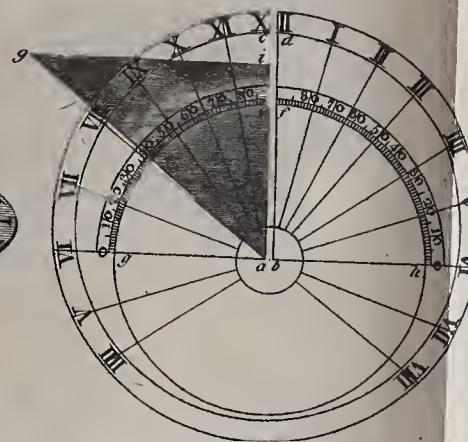


Fig. 6.

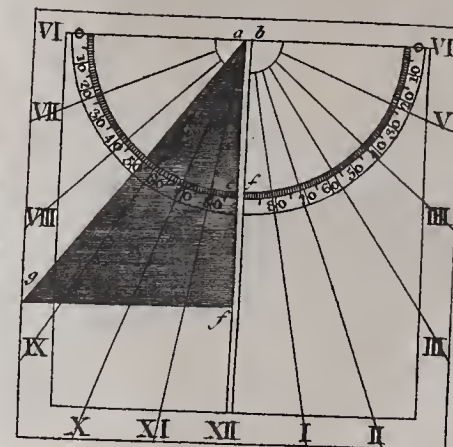


Fig. 3.

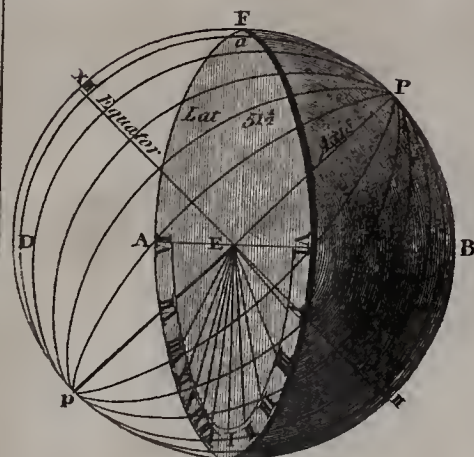


Fig. 4.



Fig. 7.

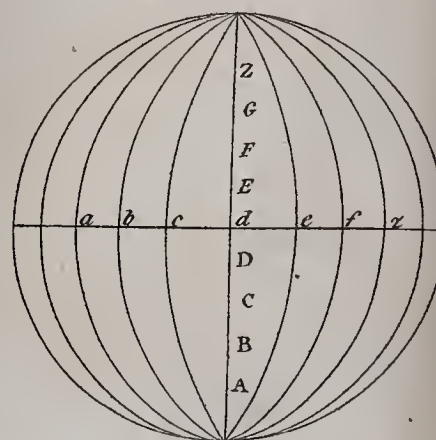


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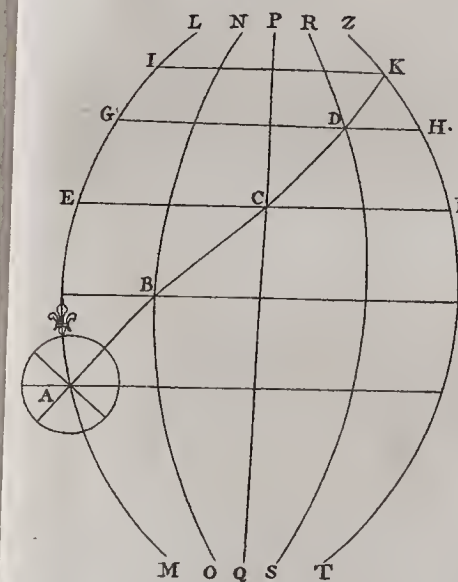


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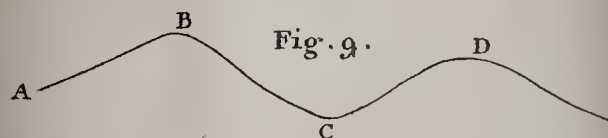
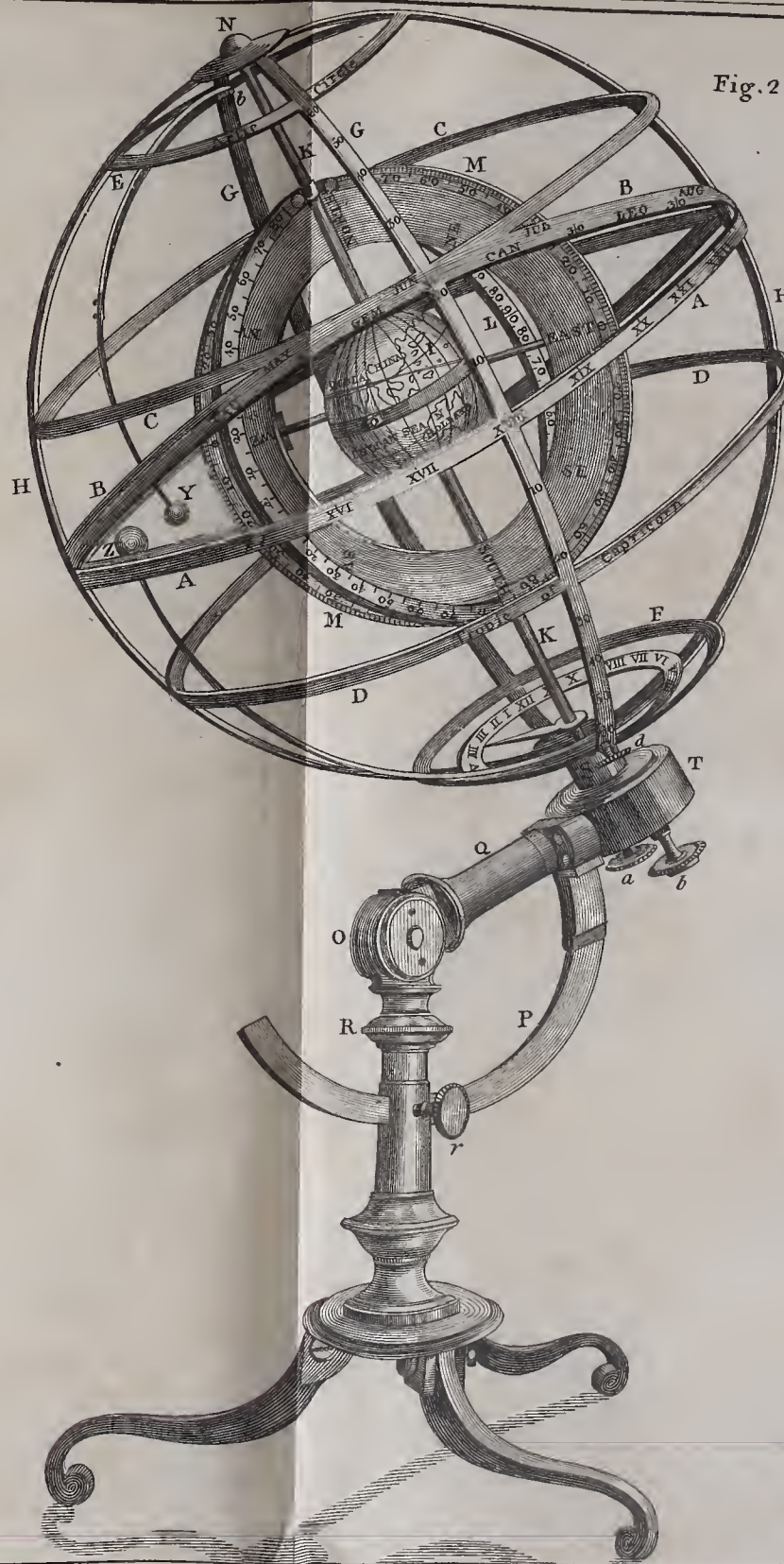


Fig. 1.



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Fig. 2.



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Fig. 1.



Fig. 2.







Fig. 2.

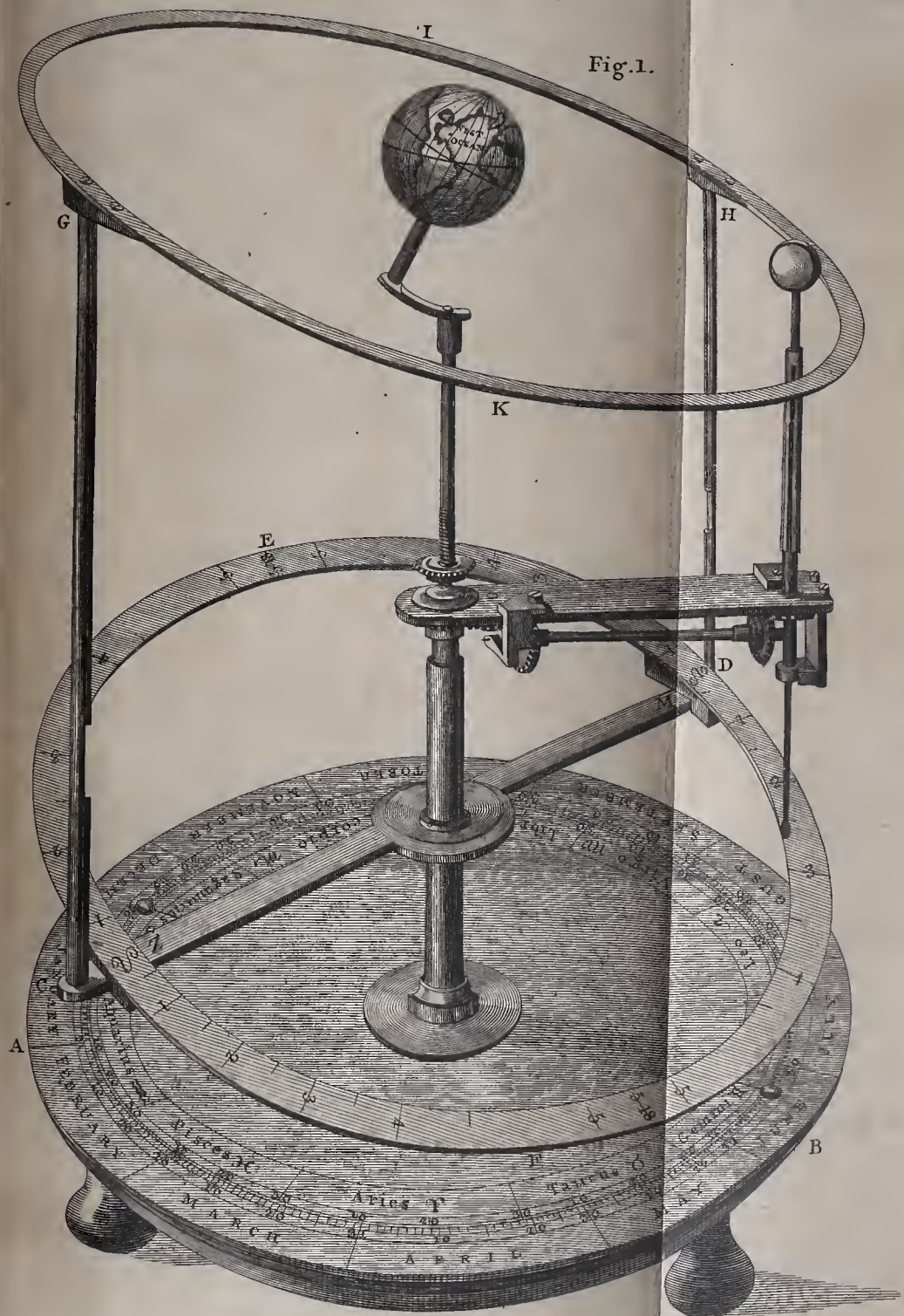


Fig. 1.

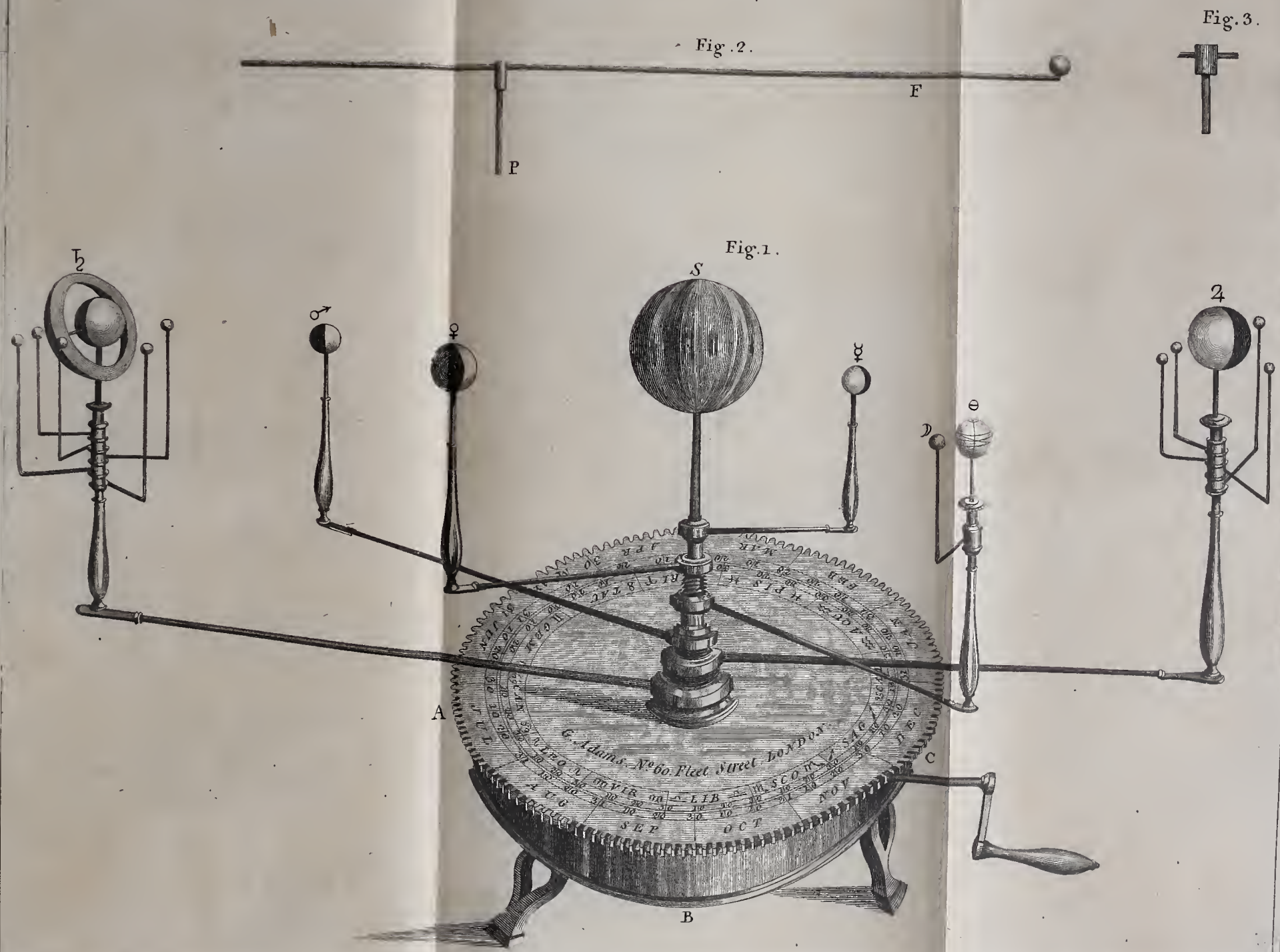


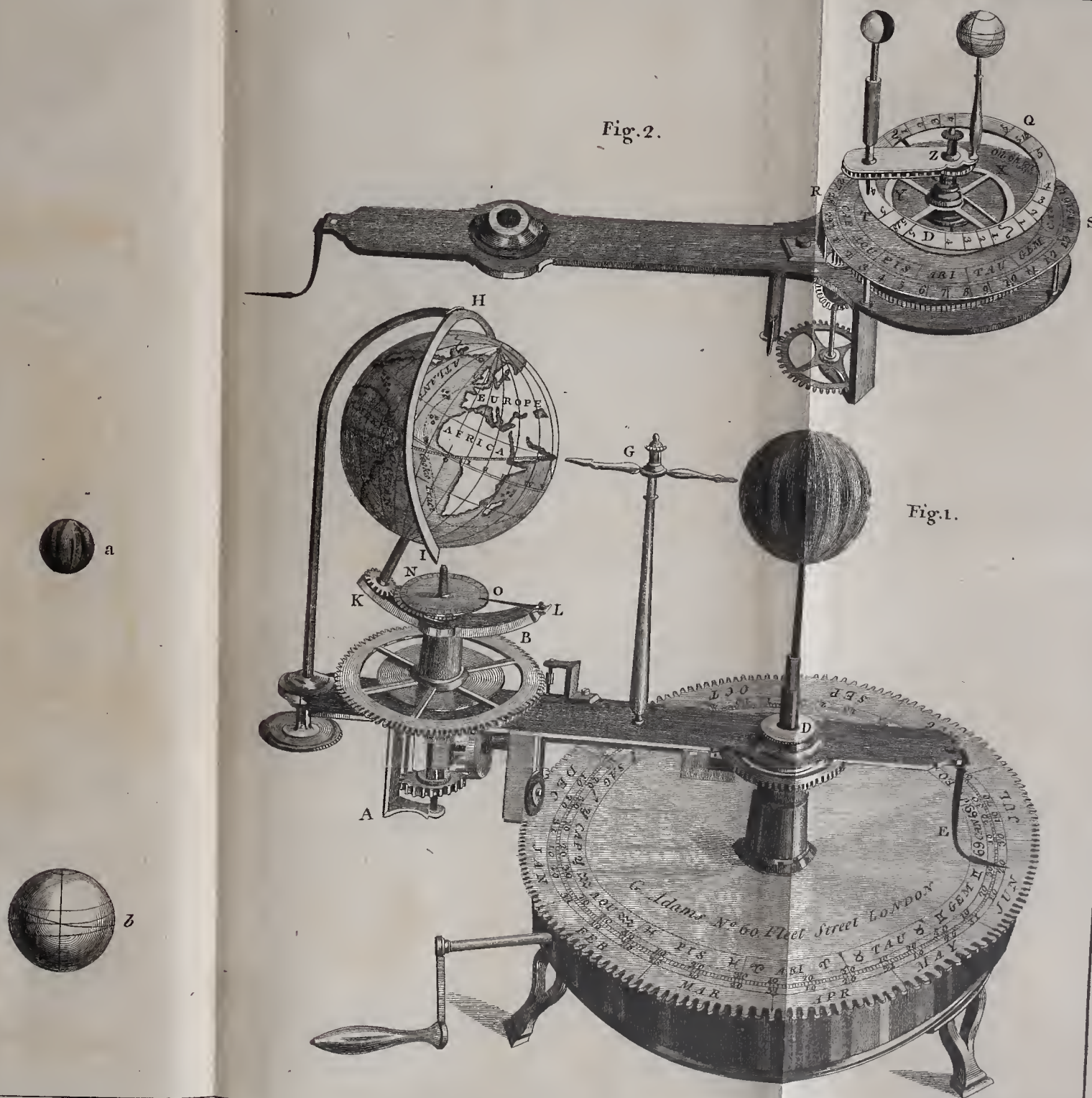
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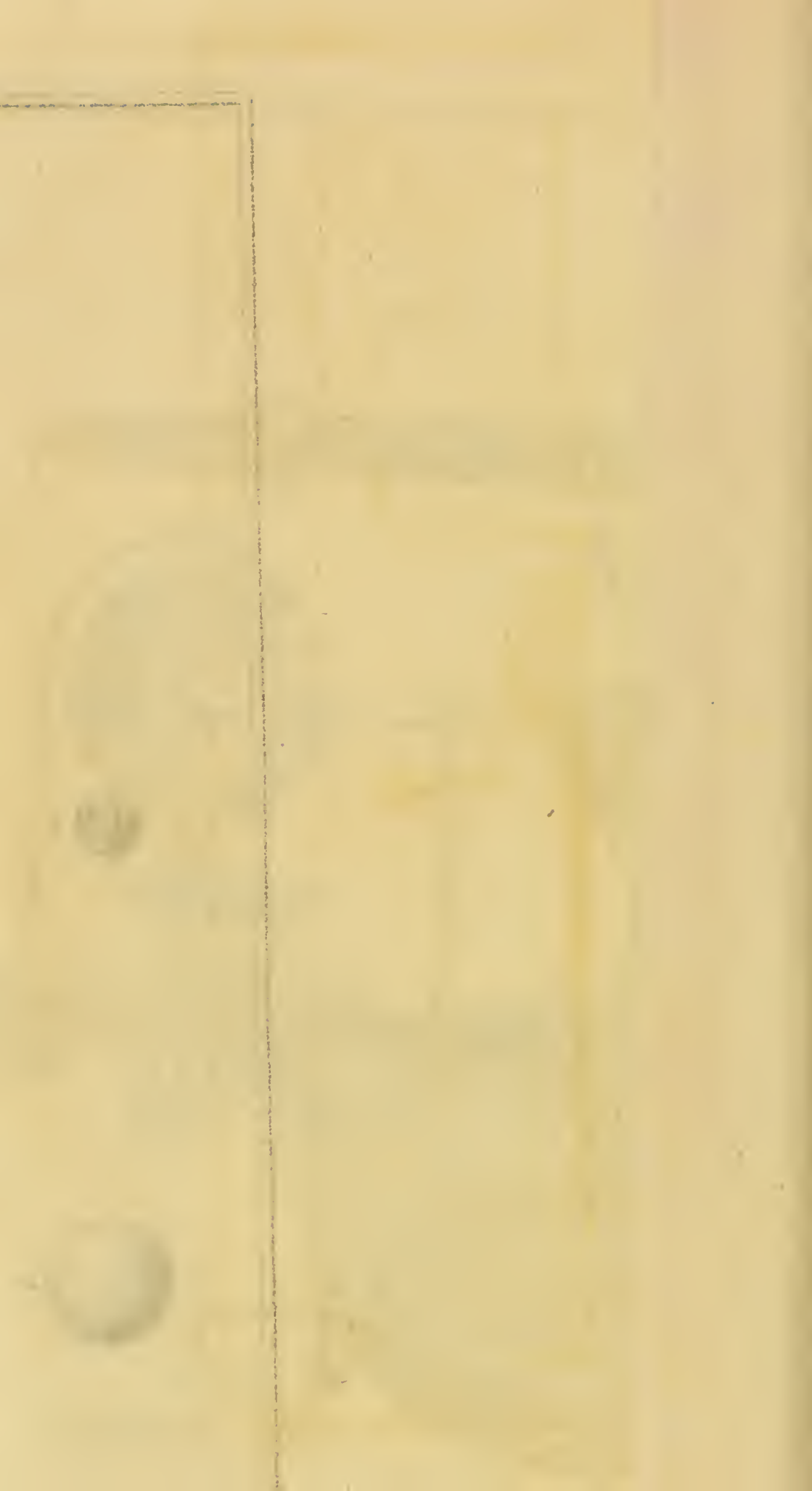
Fig. 3.

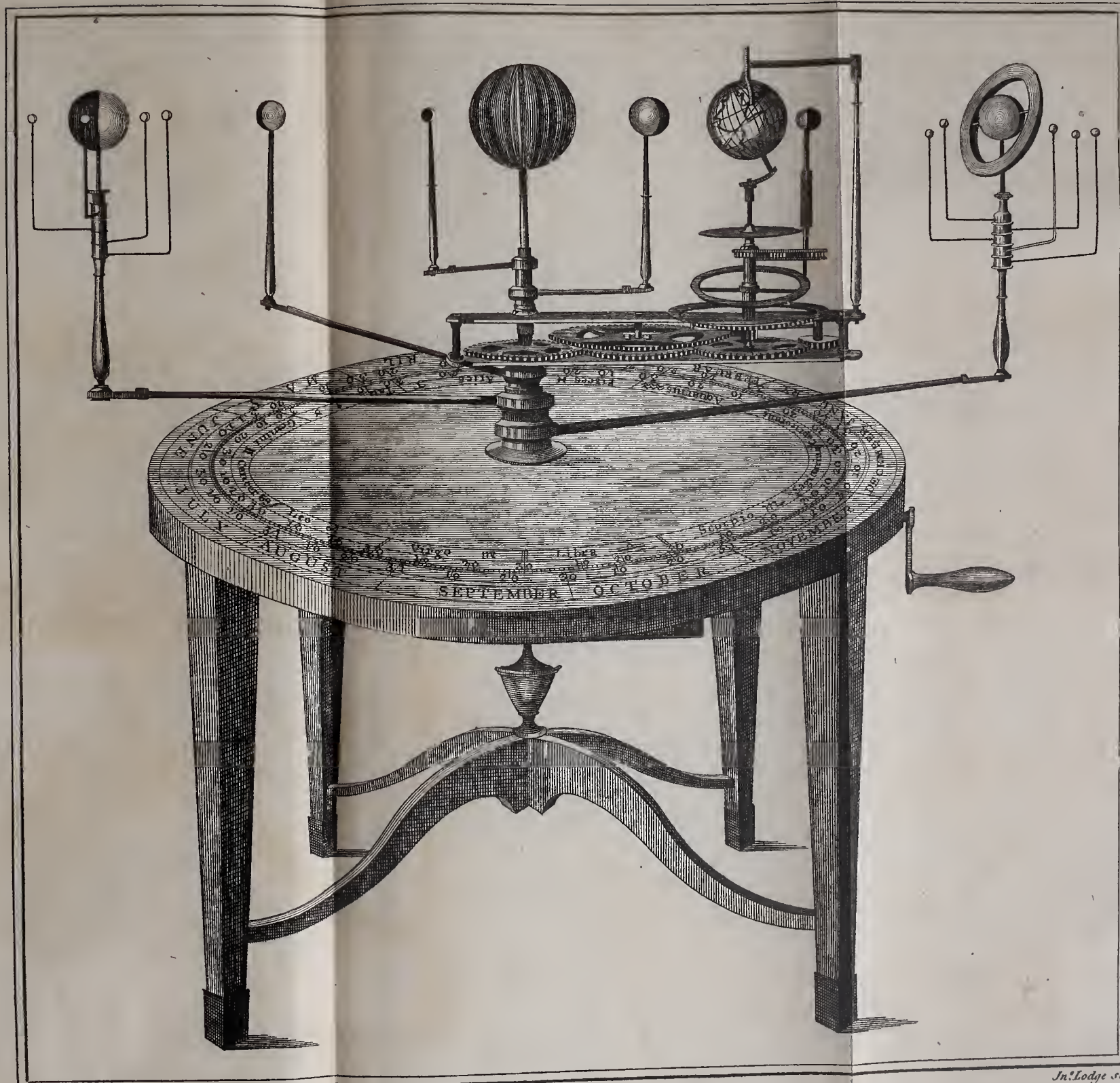
Fig. 1.

Fig. 2.

Fig. 1.







T. Milne del.

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Jn^o Lodge sc.



